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Geology of the Tertiary and Quaternary Periods in the North-West Part of Peru

With an Account of the Palaeontology

by

T. O. Bosworth

Forgotten Books

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GEOLOGY
OF THE TERTIARY AND QUATERNARY PERIODS
IN THE
NORTH-WEST PART OF PERU

BY

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D.Sc., M.A., F.G.S., F.R.G.S, M.I.P.T.

WITH AN ACCOUNT OF THE

PALÆONTOLOGY

BY

HENRY WOODS, M.A., F.R.S.
T. WAYLAND VAUGHAN, Ph.D.
J. A. CUSHMAN, Ph.D.
AND OTHERS

WITH MAPS AND NUMEROUS ILLUSTRATIONS

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PREFACE

This volume is composed of five parts, dealing with the Geology, the Palæontology, and the Oil Industry in the Petroliferous region of North-Western Peru.

The first four parts, or papers, contain conclusions resulting from the geological surveys in Peru which have been conducted by the author during the past decade, together with a study of the Tertiary Palæontology by the other writers.

As the investigation of this region was pioneer work in an unsurveyed territory, the contents of the four geological papers are wholly new. They were not originally intended for publication in book form, but were written as separate papers for the Geological Society, before which Society they were read on December 23, 1920, and were in due course accepted by the Council for publication in the Quarterly Journal.

But, owing to the large size of the work and to the quantity of illustrations, no one scientific society in the country would undertake to print the whole of it within the confines of one volume.

The author, however, considered it essential that the several papers should not be separated, nor be deprived of any of their illustrations, and therefore he decided upon independent publication as a book. Then, in order that this volume might serve an economic as

well as a scientific purpose, the fifth part was added, discussing (to such extent as the oil companies would allow) the occurrence of the petroleum in the rocks, and describing its exploitation.

The book thus becomes, to some extent, an Economic Geology of the Oilfield Region of Northern Peru. It comprises the following five parts:

I. On the Tertiary Geology. By T. O. Bosworth.
II. On the Tertiary Palæontology.[1] By Henry Woods, T. Wayland Vaughan, J. A. Cushman, and H. L. Hawkins.
III. On the Quaternary Geology. By T. O. Bosworth.
IV. On the Desert Geology. By T. O. Bosworth.
V. On the Occurrence and Exploitation of the Petroleum. By T. O. Bosworth.

The author is well aware of many of the imperfections of this book, and the reader is asked to bear in mind the difficulties under which investigations in such a region are carried out. The ruggedness of the wilderness, the heat of the equatorial sun, the lack of trails, the scarcity of food for man and beast,—and above all, the absence of water,—all render the progress of such studies laborious and slow.

As the development of this land proceeds, the work of investigation becomes very much easier. Already the oilfield locomotives—and now even motor-cars—are speeding about in some parts of the desert which were remote and totally uninhabited when the author's work was being done. In these parts, more geological observations can be made now in one comfortable day's work than could then be made in two weeks.

Thus, in course of time, a much fuller knowledge

[1] Under the title of *Illustrations of the Tertiary Fossils of Peru*, an edition of the plates of fossils was published by Messrs Macmillan & Co. on 10th April 1922.

will be gained over all the region—and many errors and inaccuracies in this present volume may be proved.

As yet, however, very little has been written about this territory, beyond a few brief articles in magazines and journals, and therefore it is hoped that this book may prove of use to those who are interested in the geology and oil resources of Peru.

None of the author's detailed geological survey maps might be published, but the several generalised maps, herein contained, should suffice to illustrate the subject. The account of the oil industry also is restricted, in deference to the wishes of certain companies.

Acknowledgments are due to many who have assisted, in one way or another, towards the production of this book.

The author was very fortunate in being able to interest Mr. Henry Woods in the fossils from this region. His study of the Tertiary Palæontology, which was a most welcome contribution, forms one of the principal parts of this volume. No Tertiary fauna of such size and importance has hitherto been found or described from the South American Continent.

Through Mr. Woods, the co-operation of several other Palæontological specialists also was obtained—Dr. T. Wayland Vaughan, Dr. J. A. Cushman, Prof. H. L. Hawkins—who have contributed important chapters and articles in Part II. The examination of the Quaternary fauna was most kindly undertaken by Col. A. J. Peile, and a special note on the barnacles was written by Mr. T. H. Withers.

Gratefully remembered are a little band of faithful followers and friends, the Peruvian workmen who

accompanied the author on his various expeditions in Peru and Ecuador throughout the period of years in which these surveys were being made—Nicholas Rodriguez, Gregorio Medina, Manuel Correa, Aurelio Abad, Floro Mogollon, Dimetrio Peralta, and several others.

The colleagues who assisted during the earliest stages of the surveys, especially Mr. H. G. Busk, also are recalled to mind with much appreciation.

With great pleasure the kindness of many friends in the oilfields is remembered—the Managers, Drillers, Office-men, Workmen, past and present; and also the Directors and Officials of the Oil Companies, particularly those of the International Petroleum Company of Toronto, Mr. H. G. Smith and Mr. A. M. McQueen, the President and Vice-President. So many are there that mention of them here would be impracticable.

Also remembered with gratitude are a number of good friends outside the oilfields, among the Peruvian landowners and citizens, in the towns and villages along the Rio Tumbes and the Rio Chira, and in Payta and elsewhere.

Thanks are due also to several gentlemen who have very kindly lent photographs for reproduction—Mr. J. Rennie, Secretary of the Lobitos Oilfields Ltd.; Mr. Beeby Thompson; Messrs. A. Beeby Thompson and Partners; Mr. A. H. Low; Mr. R. G. Sammons; Mr. O. D. Boggs.

Finally, the author is much indebted to the Publishers, Messrs. Macmillan & Company, for the care and trouble which they have taken, and for the consideration which they have shown.

T. O. BOSWORTH.

March 1922.

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PART I

STRUCTURE AND STRATIGRAPHY OF THE TERTIARY IN THE NORTH-WEST PART OF PERU

By T. O. Bosworth, D.Sc., M.A.

CHAPTER I

INTRODUCTION

The territory discussed in this paper is a strip of desert land, 15-40 miles wide, extending for 150 miles along the coast of Peru, between latitudes 3° 30′ south and 5° 20′ south.

It is bordered on the west by the Pacific Ocean and on the east by the outer ranges of the Andes. Near the north end is the little town of Tumbes and near the south end is the small port of Payta.

In this area the Tertiary has great thickness, and owing to the desert conditions it is well exposed.

The author has spent several years, during the period 1912–1918, in conducting surveys of this region. Some 4000 square miles of country have been geologically mapped, on scales varying from 3 inches per mile to $\frac{1}{4}$-inch per mile, and several hundred square miles have been mapped in full detail on a scale of 6 inches to the mile.

Geological literature[1] contains very little information about this part of Peru, and it was found necessary to commence work on blank paper and with an open mind.

[1] A paper by J. Grzybowski, "Die Tertiärablagerungen des nördlichen Peru," *Neues Jahrb. fur Min.*, etc., Beil.-Band XII. (1899), p. 611, contains some mention of the rocks and fossils. In the *Buletin del Cuerpo de Ingenieros de Minas del Peru*, No. 50, also, there is some description of the region.

A number of British mining engineers and geologists have visited the region. Among pioneers in the development of the oilfields, were Mr. John Campbell, Mr. A. Beeby Thompson, Mr. C. M. Hunter, Mr. A. Kinnaird, and other well-known engineers.

Geological reconnaissances were made by Mr. E. R. Blundstone and by Mr. C. Maddock in 1908; whilst in 1910 an examination of part of the area was made by Mr. Beeby Thompson, F.G.S., F.C.S., who subsequently read a paper to the Geological Society, in which some features of the stratigraphy were presented.[1]

The present author, during his surveys, has at times been assisted by several geologists, especially by Mr. H. G. Busk, M.A., F.G.S., in 1913. For several months in 1914 Mr. J. Romanes, M.A., F.G.S., was in the field in connection with the same work. In another part of the region geological work by Mr. C. Barrington Brown, B.A., F.G.S., and by Mr. L. V. Berry, B.A., F.G.S., has been in progress for a number of years.

The work of these geologists has contributed in one way or another to the information here set forth.

[1] An abstract only was published, *Geol. Mag.* (1913), p. 233.

CHAPTER II

GENERAL GEOLOGY OF THE REGION

GEOGRAPHY.—The region with which we are concerned is the northern part of the long strip of desert country which lies between the Cordilleras and the sea, extending southward along all the coast of Peru and far down the coast of Chile.

At the north border of the map (Folder No. I.), the Rio Tumbes comes out from the mountains and flows across the desert, reaching the sea near the town of Tumbes. The southern half of the map is likewise traversed by the Rio Chira. The area between these two rivers is the desert of Tumbes, whilst to the south of the Rio Chira lies the desert of Sechura.

Another river from the mountains—the Rio Piura—enters the south-east part of the map, but dries up before reaching the sea.

The country west of the mountains is almost devoid of vegetation, and much of it is very rugged and steep, though the altitudes are generally less than 1000 feet. Considerable parts of it are plateaus (*Tablazos*), which are dissected by many deep, trench-like canyons and dry valleys, large and small, known as *quebradas*.

Inland, there are very few inhabitants and almost no cultivation, except along the three rivers above mentioned.

On the accompanying map, lines of "latitude" and "longitude" have been drawn, at 10-mile intervals, for purposes of reference. The initial point from which they are numbered is Punta Parinas, the most westerly cape of South America.

From north to south, the principal places which will be mentioned in the following pages are :

Rio Tumbes (lat. 81, long. 63). Small river with villages along it.
Tumbes (lat. 77, long. 61). Small town of political importance.
Zorritos (lat. 70, long. 48). A mining settlement on the coast.
Mancora (lat. 40, long. 22). A small village.
Punta Organo (lat. 34, long. 12). A small cape near a curiously shaped hill which is a well-known landmark.
Cabo Blanco (lat. 29, long. 6). A well-known cape, at which the coast-line changes its general direction.
Lobitos (lat. 16, long. 4). An important oilfield settlement on the coast.
Quebrada Parinas (lat. 10). An important dry valley.
Talara (lat. 7, long. 8). A port for the petroleum industry.
Negritos (lat. 1, long. 2). An important oilfield settlement.
La Brea (lat. 1, long. 13). A landmark, 12 miles inland.
Punta Parinas (lat. 0, long. 0). The most western point of South America.
Lagunitas (lat. −2, long. 5). An oilfield settlement, 3 miles inland.
Rio Chira (lat. −16). Small river, with villages along it.
Sullana (lat. −16, long. 44). Town.
Payta (lat. −30, long. 14). A seaport.
Piura (lat. −38, long. 49). Town of political importance.
Rio Piura (lat. −38, etc., long. 49, etc.). Small river which dries up before reaching the sea.

TERTIARY
IN THE NORTH-WEST PART OF
PERU
Scale of Miles
0 5 10
T. O. Bosworth.
ECUADOR
TUMBEZ
PARINAS
PAYTA
PERU
BRAZIL
CALLAO
LIMA
BOLIVIA
LAKE TITICACA
ZORRITOS
BOCA PAN
TABLAZO
SAND
IMBEZ
to Tumbes
Tertiary
PUNTA
AMOTAPE
C. GUINEO 3000 FT.
C. PRIETO 3000 FT.
GAGUAY GRANDE
BRECCIA FAN
Not
SHALES AND LIMES
TALARA
ELEV. 450 FT.
TABLAZO
NEGRITOS
PUNTA PARINAS
LA BREA
BRECCIA FAN

Main Geological Elements of the Region.—In the region there are four main geological elements, which will now be mentioned in order from east to west.

(1) **A Range of Pre-Tertiary Desert Mountains** (the Amotape Mountains) occupies the east side of the map, rising very steeply from the desert to heights of 3000-5000 feet.

These rugged mountains, which are the most westerly range of the Andes, are composed largely of dark slates and quartzites, into which granite has been intruded. In some places they include slates and thin limestones with Palæozoic fossils. Also in their outer parts there are Cretaceous limestones (containing ammonites).

In one portion, where a large trough-fault (probably post-Tertiary) crosses the range, the mountain-mass consists of Mesozoic rocks. Presumably the range was higher in early Tertiary times, and Mesozoic rocks then formed the loftier parts.

The Tertiary Pacific Ocean reached to the foot of the mountain range. The littoral deposits of the lowest formation of the Eocene extend up the slopes to at least 600 feet above the level of the present sea.

At present, the distance from the coast to the mountains is 12-18 miles. At the south-west corner of the map, near Payta, the mountain-rocks are exposed on the coast, this being their most westerly appearance in South America.

(2) **A great Breccia Fan** forms a stony plain around the mountains, extending out from them towards the

sea, some 8 miles, and dying out on the plateaus, next to be mentioned.

This breccia deposit is more than 100 feet thick in some parts. It is of modern formation, being deposited in the flood years, which occur two or three times a century. The deposit also extends back, up all the dry valleys, into the desert mountains, in the form of thick terraces.

The Breccia Fan itself is much dissected, the deposits of each former flood being eroded by the succeeding floods.

(3) **Quaternary Deposits** of a peculiar nature cover the country west of the Breccia Fan. These are several raised sea-floors and beaches which are seen as pebbly plateaus (*Tablazos*).

The highest has an elevation of 1000 feet,[1] near Cabo Blanco, at the middle of the map (lat. 30), decreasing to 200 feet at Payta, at the south of the map (lat. −28). The deposit has a maximum thickness of 250 feet. It continues inland under the Breccia Fan to a shore-line along the edge of the mountains, 10-20 miles from the present coast.

West of this "Mancora" Tablazo is another similar marine terrace, at a lower level, the "Talara" Tablazo, 8-20 feet thick, which has an elevation of 300-350 feet, inland east of Talara (lat. 6), decreasing southward to 150 feet. West of this, again, are small fragments of the "Lobitos" Tablazo, with altitude 40-100 feet; and near the coast there are fragments of others still lower.

North of Mancora the country is much more

[1] Approximate measurement only.

denuded, owing to less arid conditions, and the Mancora Tablazo, if it ever covered this ground, has since been destroyed. The remains of several lower Tablazos, however, are present along the coast.

In places, each of the Tablazos is still preserved as far westward as the present coast, where they make steep cliffs. Formerly they completely covered almost all the territory between the mountains and the present sea.

(4) The **Tertiary Rocks** are exposed to view in a very irregular area, from which the horizontal cover of Quaternary limestones and pebble beds has been denuded away.

This ground lies chiefly along the coast where the Tablazos have been much eroded; and it extends inland up the innumerable valleys and gorges (*quebradas*), which have been cut through the Tablazos and the Breccia Fan in years of flood.

Some of the deep "quebradas" afford narrow exposures of the Tertiary all the way inland to the mountains, where the shore-line deposits are found.

In areas where the Tertiary rocks have been laid bare, the land is dissected into countless rugged hills and hillocks, many of which still carry cappings of the Tablazo beds. This part of the desert is very rough, though the height of the hills is limited to the elevations of the pre-existing marine terraces. It is swept by sand-storms, and the hills and hillocks are generally wind-cut and more or less cloaked and surrounded by blown sand.

Thus, although some 3000 square miles of country on this map—extending from the sea to the moun-

tains—is occupied by the Tertiary, more than three-quarters of this is still overlain by the Quaternary cover. The area of exposure is still further diminished by desert deposits; for in some parts there are wide spreads of sand and dunes, and along part of the sea-coast there is a belt of coastal dunes and salt-marshes (*salinas*), a mile or two in width.

Southward of this map the geology was not studied by the author, but it is known that a small area of similar Tertiary deposits is exposed, 50 miles south of Payta, near Cerro Yllesca, where the mountain-rocks again reach the sea.

To northward of this map the Tertiary continues along the coast of Ecuador and Colombia.

CHAPTER III

GEOLOGICAL STRUCTURE IN THE TERTIARY

Block-Faulting of the Tertiary.—Underneath the Quaternary deposits, the Littoral is traversed by a close and elaborate network of faults. By these faults the Tertiary accumulation has been cut up into countless separate blocks, each having its own independent strike and dip. (See Folder No. II.)

This block-faulting is conspicuous throughout the area, wherever the cover of horizontal Quaternary has been removed. Under desert erosion the shales and sandstones of the Tertiary tend to crop out as an orderly succession of parallel ridges, with plane dip-slopes, nearly as regular as house roofs. As a rule the ridges are terminated at both ends by faults, and so each fault-block is seen as a separate topographic unit, consisting of a ridge or group of parallel ridges. Some of these units are as large as a town or a village, others have the size of a row of buildings, and a great number are no larger than a church or a house.

Standing on a hill-top it is often possible to follow the network of faults with the eye—each large fault appearing as a line of topographical discontinuity, with ridges ending abruptly on either side of it. Faults of less magnitude make smaller gaps or irregularities in the ridges; and a multitude of small

faults are exposed to view on the hill-sides and valley sides, and also on the bare, flat ground.

Where the Tertiary is exposed actually lying on the older rocks, along the margin of the mountains, it is seen that these mountain rocks also are affected by the faults.

The Quaternary beds do not participate in the block-faulting, and evidently the movements occurred during an interval which preceded their deposition. (The remarkable oscillations which took place during the Quaternary are dealt with in Part III.)

The Faults and Crush-belts.—The faults are countless in number. They vary in importance from mere fractures up to master faults, some miles in length, having several thousand feet of throw. The shifting of the outcrops by the large faults is sometimes as much as a mile or two.

The greater faults are belts of intense crushing, sometimes a quarter of a mile or more in width, in which the rocks are "milled" often beyond recognition.

Some of these faults can be drawn on the maps with ramifications and "loops," by which many small masses of harder rocks (forming separate hills and hillocks), are entangled in the crush-belt, although far removed from the outcrops of the main body to which they belong. Occasionally, also, masses of arched and crumpled clay-shale are included.

Commonly the soft "greda" within the crush-belt has lost all trace of bedding and has acquired a homogeneous appearance. Often this is softer than the adjacent unbroken strata, and a depression can be traced across country, marking the line of the

fault. Generally, however, this pale, crushed clay-shale contains concretions and lenticles, composed of calcite, gypsum, and clay; and sometimes it includes sandstone-balls, up to a foot in diameter, each consisting of a piece of sandstone, rolled and compressed, and surrounded by a shell-like coating of calcitic or gypseous material. In these cases the crush-belt may be harder than the surrounding rocks, and may weather out as a slight ridge.

The rocks contiguous to the large faults are somewhat affected by the movements. Frequently their strike is deflected; and sometimes a kind of "packing" of the beds may have occurred, by which some "wedges" have ridden over and under others, in an irregular manner. Approaching the faults, the beds are veined with calcite along many small fractures; and sometimes certain calcareous and fossil-bearing bands gradually become discontinuous, and finally are represented by seams of calcareous lenticles which have shell-like outer layers of cone-in-cone structure. Often there are regular seams, up to six inches thick, of this "cone-in-cone" material.

The Fault-blocks and their Attitude.—In certain districts where the rocks are bare and where fossils are abundant (particularly in the ground occupied by the Negritos Formation), the geology has been mapped in detail and the fault-system is known.

Here it is found that the large faults generally have no particular tendency to follow either the direction of strike or dip. They cross the outcrops obliquely and converge at many points.

The land surface is thus divided into long triangles

and elongated quadrilaterals, outlined by faults of considerable displacement. These larger blocks are further cut up into many parts by smaller faults; and except in places where the dip is low, even the smallest hillocks are seldom entirely free from faults. Not only are the larger blocks, having areas of several hundred acres, bounded by these master faults, but many masses of rock covering only an acre or a tenth of an acre, are parted from their neighbours by vertical displacements of a thousand feet or more.

The accompanying plan (Folder No. II.) on a scale of $\frac{1}{10}$ inch to the mile, shows some of the large fault-blocks, 10-15 miles from the mountains, near the middle of the strip of country under consideration; but only a large-scale map can convey any adequate idea of the number of faults and the intricacy of the structure.

The attitude of the fault-blocks does not follow any definite plan. The strike and dip varies irregularly from one block to another, though many neighbouring blocks may differ only slightly in direction.

Along the edge of the mountains the strike is in a general north-east direction, parallel to the range, and the dip is to seaward at angles of 5°-25°.

Farther from the mountains the strike and dip may have any direction, though there is still some tendency to trend parallel to the range.

Along the coast the blocks have many different directions and often the dip is as much as 30°. Thus, from Tumbes to Mancora, the blocks along the coast, which consist of the Zorritos Formation, dip mostly to the north or north-west at 10°-30°.

From Mancora to Cabo Blanco the Lobitos

Formation is exposed, dipping generally north or north-east, at 7°-20°.

Around Cabo Blanco, blocks of the Negritos Formation are seen, inclined to the north-west and in various other directions at about 20°.

From Lobitos to Talara the Lobitos Formation is exposed. Here the blocks dip to the north-east, east, and north, at 20°-30°.

From Talara to Parinas Point members of the Negritos Formation have been brought up to the surface. These blocks strike north and south, and are tilted towards the mountains at 20°-30°.

Farther southward along the coast, towards the river Chira, the Lobitos Formation is at the surface, dipping to north or north-east at 5°-15°.

The amount of differential movement between the blocks often is large. In some places, beds whose stratigraphic horizons were 4000-6000 feet apart, are now outcropping at the surface side by side. Thus about the middle of the map the Turritella Series of the Negritos Formation are seen on the coast, 15 miles west of the mountains; and in contact with them on the north side, and also on the south side, are beds of the Lobitos Formation, some 6000 feet higher stratigraphically. Continuing inland, each of these formations is repeated several times, and on the mountain flanks the Clavilithes Series of the Negritos Formation are found at an elevation of 600 feet.

The continuity of some of the fault-blocks below ground has been proved to depths of 3500 feet by borings, certain beds having been explored from the outcrop down the dip to this depth. (See Folder No. III., B, and Fig. 144.)

CHAPTER IV

GENERAL STRATIGRAPHY AND PALÆONTOLOGY OF THE TERTIARY

Owing to the smallness of the fault-blocks and the discontinuity of the exposures, the sequence of the Tertiary deposits is not easily unravelled. Had the rocks been further obscured by vegetation, as they are to the north in Ecuador, or had there been a scarcity of fossils, the facts could not have been determined.

The whole of the Tertiary exposed, consists of alternations of clay-shales and sandstones. Throughout the greater part of it, clay-shales predominate, though in certain portions there is a preponderance of sandstone. Neither the top nor the bottom of the system has been found. The thickness of the known deposits is estimated at 15,000-25,000 feet.

The Tertiary is divisible into three main formations, which have been named from the districts in which they are well developed and also are well known.

[Table

Photograph by T. O. Bosworth.

Fig. 1.—A view of the Turritella Series of the Negritos Formation, $2\frac{1}{2}$ miles N.E. of Punta Parinas, and 1 mile N.E. of Negritos.

The dip-slope, conspicuous in the right foreground, is formed by a seam of pebbles and fossils.

Photograph by I. O. Bosworth

FIG. 2.—Surface of a fossil-seam in the Turritella Series, crowded with *T. negritosensis*, sp. nov. (Viewed from above.) One mile E.N.E. from Punta Parinas.

The Tertiary Formations

Zorritos Formation, 5000 *feet* + Exposed extensively in the north part of the region (but little studied); absent or denuded from the south part. Clay-shales and sandstones. Fossils—all different from those in formations below.
Lobitos Formation, 5000 *feet* + Exposed mainly in the middle and south parts of the region. Clay-shales, with thick and thin beds of calcareous sandstone containing *Nummulites*, etc. Southward this passes into a mass of clay-shales with or without some thin seams of sandstone and pebbles. Fossils—chiefly discoidal foraminifera, but in places some gasteropods and pelecypods.
Negritos Formation, 7000 *feet* + Exposed in the middle part of the region. Clay-shales, sandstones, and seams of beach pebbles, with many fossils. Consists of two members: Clavilithes Series, 4000 feet. Turritella Series, 3000 feet +. Fossils—chiefly gasteropods and pelecypods. *Aturia* present.

These three formations of the Tertiary, and their occurrence, will be briefly described in the following three chapters, in order commencing with the oldest.

A rich fauna is found in the Tertiary of this region, the quantity of fossils in some members of the system being quite remarkable.

In the course of these surveys more than 20,000 specimens were gathered. These were studied in the field, so far as was practicable, without reference to literature; and the species were given provisional names for field use. By means of the fossils the main natural divisions were distinguished.

The lowest formation (Negritos Formation) was found to be especially rich in gasteropods, and by the use of them it was easily divided into two series, one of which contains a large quantity of *Turritella* of several species, whilst the other is distinguished by the presence of several species of *Clavilithes*, together with a multitude of a small form of *Turritella* (*T. anceps*, sp. nov.). With the aid of many other species, these were further subdivided.

The middle formation (Lobitos Formation) was found to be comparatively poor in mollusca, but was characterised by the presence of discoidal foraminifera (*Nummulites*, etc.).

The upper formation (Zorritos Formation) occurring in the north part of the map, was found to be rich in gasteropods and pelecypods, all different from those in the beds below. Probably this formation could easily be further subdivided.

The most conspicuous feature of this Tertiary fauna, both as regards species and individuals, is the quantity of gasteropods.

Although only a few of the species could be identified with any known in other lands, there was sufficient evidence to indicate that the whole 12,000

Photograph by T. O. Boswell.

FIG. 3. The Negritos Formation, 1 to $1\frac{1}{2}$ miles N.E. of Negritos, viewed looking in a S.E. direction.

The beds in the foreground belong to the top part of the Turritella Series. They are dipping eastward at 22°–25°.

Photograph by O. D. Boggs.

Fig. 4.—Typical view of the Turritella Series, ½ mile east of Negritos, looking north-eastward.

In the left part of the picture, just beyond the derrick, a valley crossing the strike marks the position of a fault. Near the right edge of the view, an irregularity in the ridge has been caused by a small fault. The left skyline is formed by the Talara Tablazo.

feet or more of the Negritos and Lobitos Formations is of Eocene age.

Many of the species occur throughout several thousand feet of strata, and some of them were found to have undergone progressive change. In the cases of *Volutospina peruviana*, sp. nov., *Venericardia planicosta*, and some others, this was helpful in the field work.

The collections have now been studied by Mr. Henry Woods, F.R.S., by whom most of the species are described and named in Part II. of this work.

CHAPTER V

THE NEGRITOS FORMATION OF THE TERTIARY

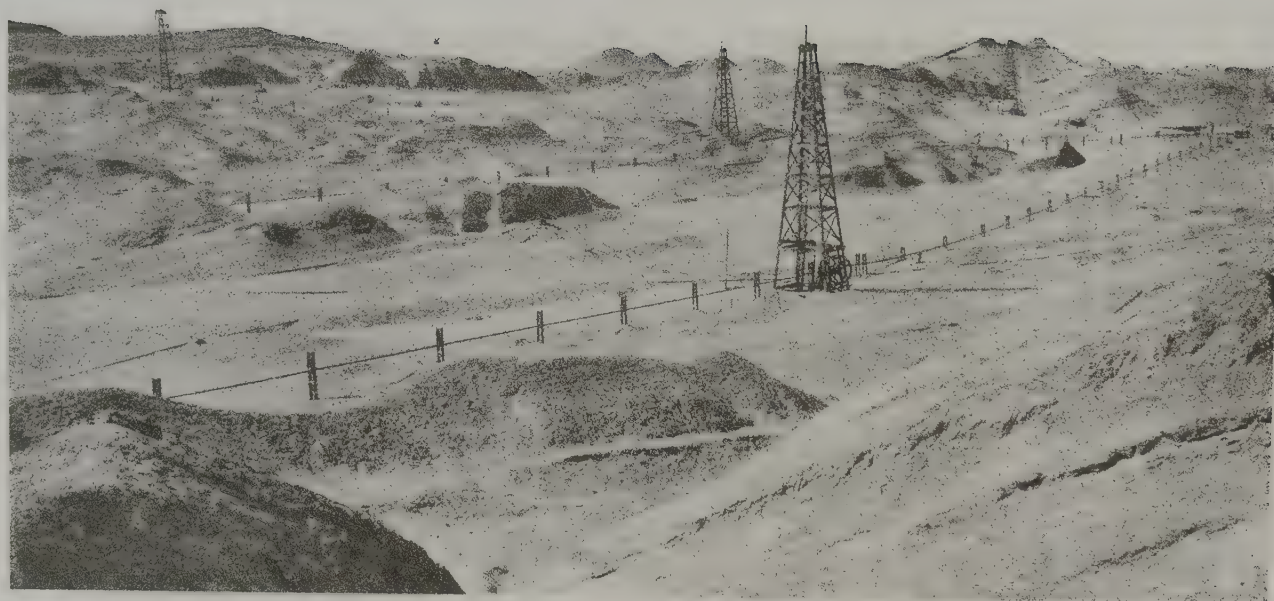
THE Negritos Formation, which is perhaps the most interesting part of the Tertiary, is seen at the surface in only a small fraction of the area. In the remainder, it is presumably underground. The exposures occur in five separate localities.

(1) NEGRITOS FORMATION IN THE NEGRITOS DISTRICT

In the Negritos district, the formation is fully exposed over some 16 square miles of bare and much-dissected "bad-lands." Here it has been studied and mapped in detail on the scale of 6 inches to the mile. As the area is intensely faulted, the accompanying map (Folder No. II.), which is on a reduced scale, can show only a simplified version of the geology.

The main constituent of the Negritos Formation is a well-bedded clay-shale ("greda") of a blue-grey colour. This shale is of fine texture, though often containing a considerable proportion of very fine quartz sand. Much of it is crowded with minute carbonaceous particles which, in the coarser seams, are just large enough to be recognised, with the lens, as fragments of leaves and slender stems.

Alternating with the beds of clay-shale, at intervals



Photograph by T. O. Bosworth.

Fig. 5.—The Turritella Series of the Negritos Formation, at Negritos, dipping to E.S.E. at 27°. View looking south-eastward from a point immediately south-east of Negritos.

Photograph by T. O. Bosworth.

FIG. 6.—Surface of a fossil-seam, near the top of the Turritella Series, crowded with *T. Lissoni*, sp. nov. (Viewed from above.) Two miles E.N.E. of Punta Parinas.

generally of from 10 to 100 feet, there are many beds of sandstone, of medium grain, often having a faint pink tint at outcrop. The majority of these bands are only a few feet thick, but a number of them attain to 20 feet or more. There are also sand-shales abundant in some places and beds composed largely of fine sand, with but little lamination, which might be called either sandy clay-shale or argillaceous sandstone. Numerous thin, dark red, ferruginous seams also are conspicuous. These, being harder than the shale, form many of the smaller dip-slopes.

Pebble beaches are an interesting feature of this formation. Resting on almost every sandstone bed, and also between many of the beds of shale, these seams of loose pebbles are seen. Most of the seams are only a few inches thick and consist of pebbles of 2 inches diameter and less; but some are thicker, occasionally 5-10 feet, with pebbles up to 6 inches diameter.

The stones are obviously beach pebbles, greatly worn and of flattened shape. The pebbles are chiefly quartzites of several kinds and colours, dark quartz schists and quartz-mica schists, and various igneous rocks, especially pale-coloured andesites and porphyrites. They are quite different from the pebbles in the Quaternary, but, like them, they have not been derived (except perhaps to a small extent) from the mountains nearest at hand.

These fossil beaches, which are somewhat lenticular and variable, are almost countless in number. Many of them are crowded with marine shells, or have a thin layer of shells scattered over them. (In

the beds of clay-shale, fossils are rare or absent, and within the sandstones they are not often present.)

The fossils are of such kinds as would be expected on a beach. Many of the shells are broken and eroded, and seldom are two valves found together. There are also many bits of coral, and pieces of driftwood, worm-eaten and riddled by boring shellfish. On weathering, these fossil logs crumble to pieces and leave the ground strewn with the shells which were in them.

The fossils are well preserved in hard calcite; those in the Turritella Series generally are brown and ferruginous, whilst those in the Clavilithes Series often are white or only slightly coloured. Being harder than the shales and sandstone, these fossil seams weather out in relief, forming the bare dip-slopes of the ridges, and presenting to the observer plane surfaces covered with almost clean shells. (See Fig. 1 and Fig. 87.)

The stratigraphy of the Negritos Formation is best displayed a mile or two north-east of Parinas Point. By selecting the largest and least fractured fault-blocks, it is possible to walk across the outcrops of the whole of the exposed 5500 feet of strata, in a distance of 2½ miles. (See Folder No. III., B.)

The formation in this district consists of the following members:—

[TABLE

THE NEGRITOS FORMATION AT NEGRITOS

CLAVILITHES SERIES, 4000 *feet*
e. PARINAS SANDSTONE (1000 feet). Massive brown sandstone, and beds of sandstone and conglomerate, with some beds of clay-shale. Characteristic fossils : *Clavilithes pacificus*, sp. nov., *Pseudoglauconia Lissoni*, *Morgania magna*, sp. nov., *Turritella annectens*, sp. nov.
d. PALE SHALES (2000 feet). Clay-shales with thin, red, ferruginous seams; some thin beds of sand-shale; few sandstones, few pebble-seams. Fossils generally scarce—*Turritella*, forms connecting *T. anceps* and *T. annectens.* Passage-beds near top, with irregular sandstones, and occasionally many fossils, which include some new species characteristic of Parinas Sandstone.
c. SHALES WITH PEBBLE SEAMS (1000 feet). Blue-grey clay-shales with bands of sandstone, and many seams of beach pebbles, crowded with fossils. Fossils very abundant—*Turritella anceps*, sp. nov., *Melanatria acanthica*, sp. nov., *Surcula occidentalis*, sp. nov., *S. Thompsoni*, sp. nov., *Clavilithes peruvianus*, sp. nov., *Volutospina peruvianus*, sp. nov.

TURRITELLA SERIES, 3000 *feet* +
b. SHALES WITH PEBBLE SEAMS (1500 feet). Blue and grey clay-shales, with sandstone bands and many seams of beach pebbles, crowded with fossils. Fossils very abundant, especially *Turritella* of several species.
a. SHALES UNEXPOSED (1500 feet +). Probably similar to those above, but known only in bore-holes. Base not found.

Folder No. II.

Note.—*Geological Map*, Folder No. II., was prepared from detailed maps on scale 6 inches = 1 mile. The geology has been much simplified on this present small-scale plan.

In this field the outcrops of the Tertiary are concealed by desert sand to the extent of half the area. On the map, only the larger spreads of sand are indicated.

The Quaternary, which covers the Tertiary in some parts, especially in the north-east, is not indicated.

Small exposures are exaggerated for the sake of clearness in the following places:

> Lobitos Formation near lat. 0, long. 0, and near lat. – 1, long. 0; the Pale Shales at lat. 2, long. 2, and at lat. – 2, long. 2; the Turritella Series at lat. – 1½, long. 3½; etc., etc.

Much of the smaller faulting is omitted, and in the areas occupied by sand there are large faults which have not been shown because their positions are uncertain. In a number of places single fault-lines have been drawn where the faulting is really complex.

There are wide crush-belts which, to avoid confusion, have been shown only by fault-lines. The rocks indicated as Pale Shales in long. 5-5½ are crushed beyond certain identification, and might perhaps be Lobitos Formation. There are similar uncertainties due to crushed condition of the rocks in small areas south-west of lat. 2, long. 2; around lat. 1, long. 3; etc.

It is not necessary to describe the strata in detail, but a few of the prominent beds and fossil horizons are mentioned below.

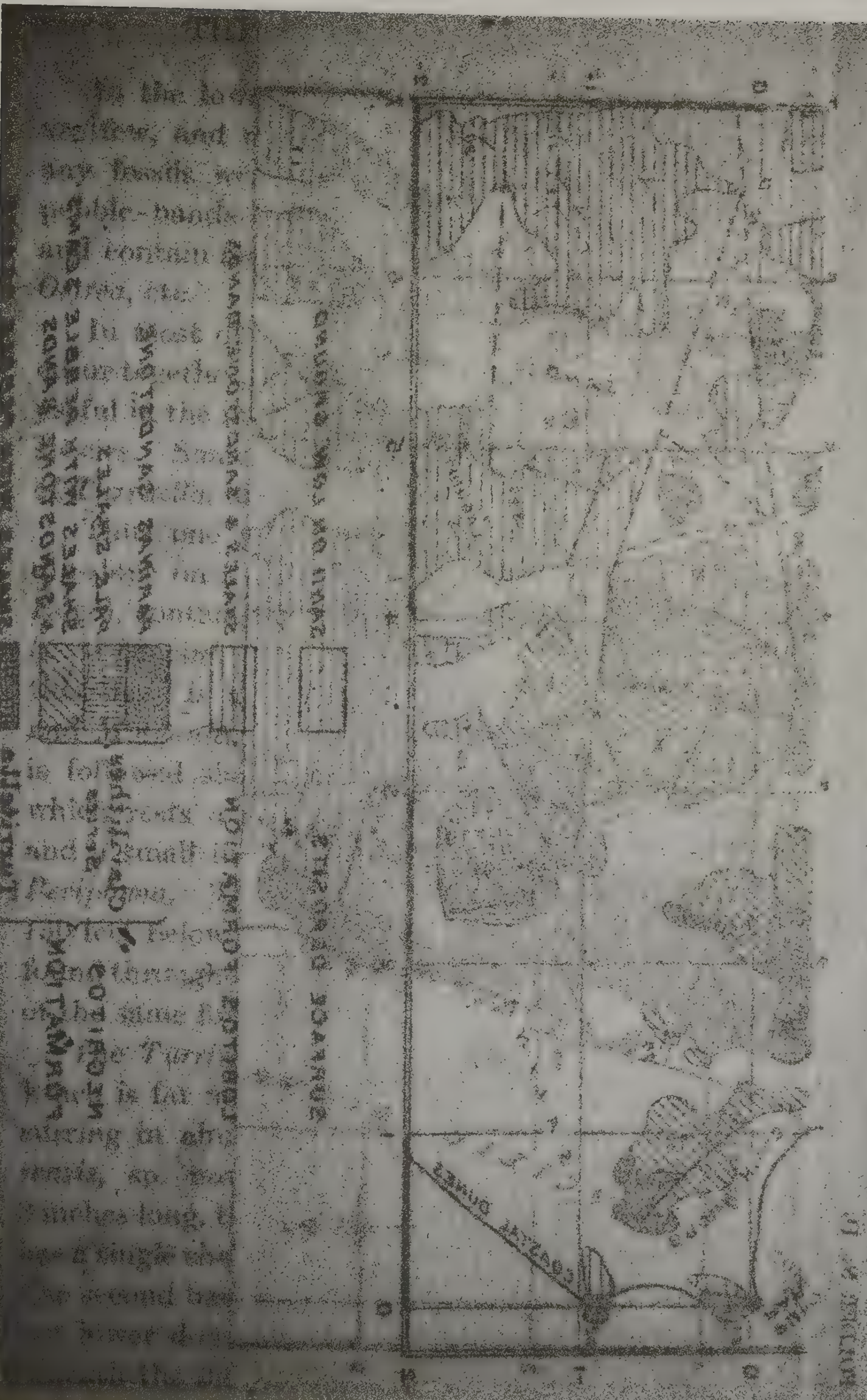
Turritella Series (3000 feet +)

(*a*) "shales unexposed" (1500 feet).

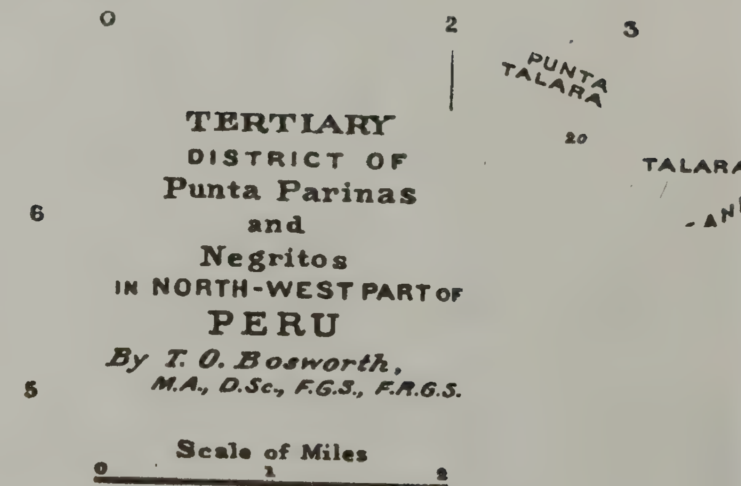
Regarding the lowest 1500 feet of strata known, there is little information, except that, to the drillers, they appeared similar to the overlying beds. They consist of clay-shales with some sandstone bands and pebble seams. It is not known how far below them the pre-Tertiary rocks lie.

(*b*) "shales with pebble-seams" (1500 feet).

The whole of these strata are amply exposed. They consist of clay-shales with many beds of sandstone and seams of pebbles.



FOLDER No. II.


0
2
3
PUNTA TALARA
20
TALARA
AND
6
5
TERTIARY
DISTRICT OF
Punta Parinas
and
Negritos
IN NORTH-WEST PART OF
PERU
By T. O. Bosworth,
M.A., D.Sc., F.G.S., F.R.G.S.
Scale of Miles
0
1
2

In the lowest 400 feet exposed, the pebble seams are few, and except for an occasional *Ostrea*, hardly any fossils were found. But above these beds, the pebble-bands and fossil seams become numerous; and contain an abundance of *Turritella*, *Venericardia*, *Ostrea*, etc.

In most of the fossil seams, many different fossils occur together, but there are also some bands, specially useful in the mapping, which are devoted to particular species. Some seams consist mainly of *Ostrea*, others of *Turritella*, and so on. (See Figs. 2, 6, 7, 8, 12.)

Thus one pebble band, which is well seen as a dip-slope on a long ridge (which was named Straight Edge), contains many specimens of a spiny *Cerithium* (*C. Chatwini*, sp. nov.). A short distance above this there is a thick pebble band, containing *Ostrea* and *Morgania*, which forms a prominent ridge. This is followed shortly by a bed of white sandstone on which rests a layer of small *Turritellas* (*T. Lissoni*) and a small inequivalve lamellibranch somewhat like *Periploma*. This seam is almost continuous at about 150 feet below the top of the Turritella Series, and was found throughout this district. One or more other seams of the same fossils occur lower down in the series.

The *Turritella*, which distinguishes the series, and which is far more abundant than any other fossil, occurring in almost every fossil seam, is the *T. negritosensis*, sp. nov. Of this shell, which grows about 3 inches long, there are several varieties. The simplest has a single sharp strong keel on its whorls throughout. The second has, in the early whorls, only a single keel, but lower down on the shell an additional keel, just beneath the first, is gradually introduced. The third

form has the double keel practically throughout. These three varieties, and gradations between them, are all abundant, and seem to be equally distributed. Less numerous are other forms, in which towards the base of the shell, a triple keel is developed.

Of the larger gasteropods the most notable is a stout *Melanatria* or *Pseudoglauconia* (*P. Lissoni*), 6 inches in length, which occurs plentifully throughout the Negritos Formation, and is present also in the lowest beds of the Lobitos Formation.

Clavilithes Series (4000 feet)

(*c*) "shales with pebble-seams" (1000 feet).

The transition from the Turritella Series to the Clavilithes Series is not marked by any notable lithological change. There is still the same alternation of clay-shales, thin sandstones, and beach-pebble seams.

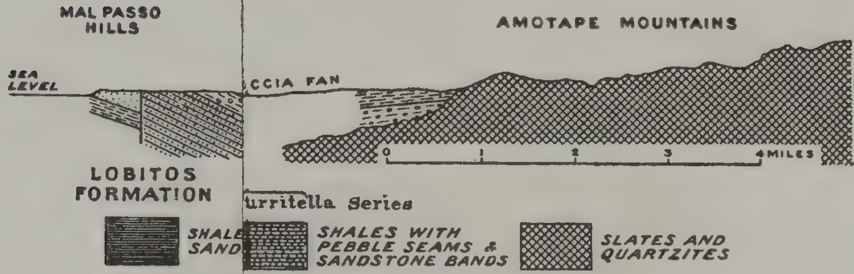
Some slight but abrupt changes in the fauna distinguish these beds from the series below.

The *Turritellas*, which were so abundant in the Turritella Series—*T. negritosensis*, sp. nov., *T. Lissoni*, sp. nov., and *T. Douvillei*, sp. nov., and also *Cerithium Chatwini*, sp. nov., suddenly disappear and occur no more. Only in two or three places, at the junction, were any of these species found in company with the *Turritella anceps*, which marks the commencement of the Clavilithes Series. (At La Brea, 12 miles inland, there is a seam of *T. Lissoni*, sp. nov., near the base of the Clavilithes Series.)

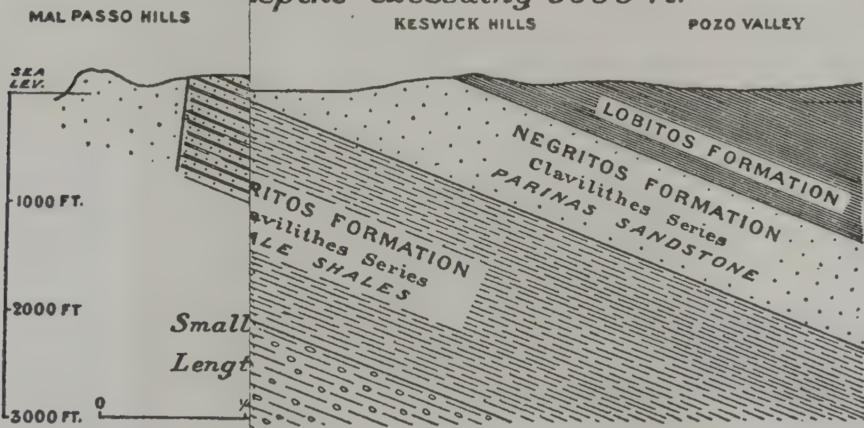
The other gasteropods, which were numerous in the Turritella Series, continue in the Clavilithes Series, and most of them are plentiful.

FOLDER No. III.

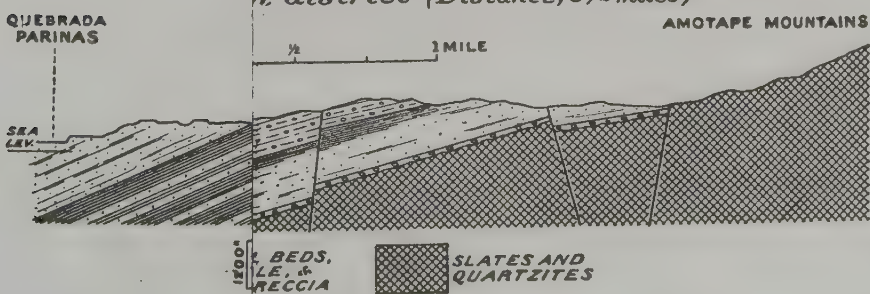
A *Simplifiec o Hills, to the Amotape Mountains*
tical Scales the same.



B *Geological Sec ground in the Punta Parinas district*
lepths exceeding 3000 ft.



C *Sn. district (Distance, 6½ miles)*



Photograph by T O Bosworth

Fig. 7.—Surface of the Surcula Bed, at the base of the Clavilithes Series. (Viewed from above.) Two miles east of Punta Parinas.

Photograph by T. O. Bosworth.

FIG. 8.— A fossil-seam in the Clavilithes Series, crowded with *Turritella anceps*, sp. nov
Two miles east of Punta Parinas.

A number of species which formerly occurred sparingly, now become abundant, especially *Olivancillaria eocenica*, sp. nov., *Strepsidura pacifica*, sp. nov., *Melanatria acanthica*, sp. nov., and *Diastoma americanum*, sp. nov.

Chief among the new fossils is the *Turritella anceps*, sp. nov., which, above the Surcula Bed, abounds in almost every fossil band. Some seams are composed almost wholly of it. (See Fig. 8.)

The pelecypods are practically the same as in the Turritella Series. *Ostrea*, however, is less numerous, whilst *Meretrix* becomes plentiful.

The corals are the same as in the beds below, and the cephalopoda are still represented by *Aturia*.

The lowest bed of the Clavilithes Series in the Negritos district is commonly a pinkish-white sandstone, some 5 or 10 feet thick, upon which lies a seam of fossils containing a profusion of spiny *Surcula*, together with *Volutospina*, *Melanatria*, *Clavilithes*, and many other shells (Fig. 7). This Surcula Bed is fairly persistent, and generally contains neither the Turritellas characteristic of the beds below nor the *T. anceps* of the beds above. Traced northwards the bed becomes more shaly, and there are in it a few *T. anceps* and also some small specimens of the *Clavilithes pacificus*, which becomes characteristic of the Parinas Sandstone beds higher up.

In some localities a seam, almost entirely composed of *Meretrix*, occurs a short distance above the Surcula Bed.

A rather persistent horizon, near the top of this group of beds, which was used in the mapping, is a seam containing many crabs.

(*d*) "THE PALE SHALES" (2000 feet).

In the next 2000 feet of strata, the sandstones, sand-shales, and the pebble seams are less frequent, and the general appearance of the outcropping mass is paler and more monotonous.

Fossils are much less plentiful, but where present, are little different from those of the beds below, except for the modifications which several species undergo. The *Turritella anceps* here present is a form grading from *T. anceps* towards *T. annectens*, sp. nov.

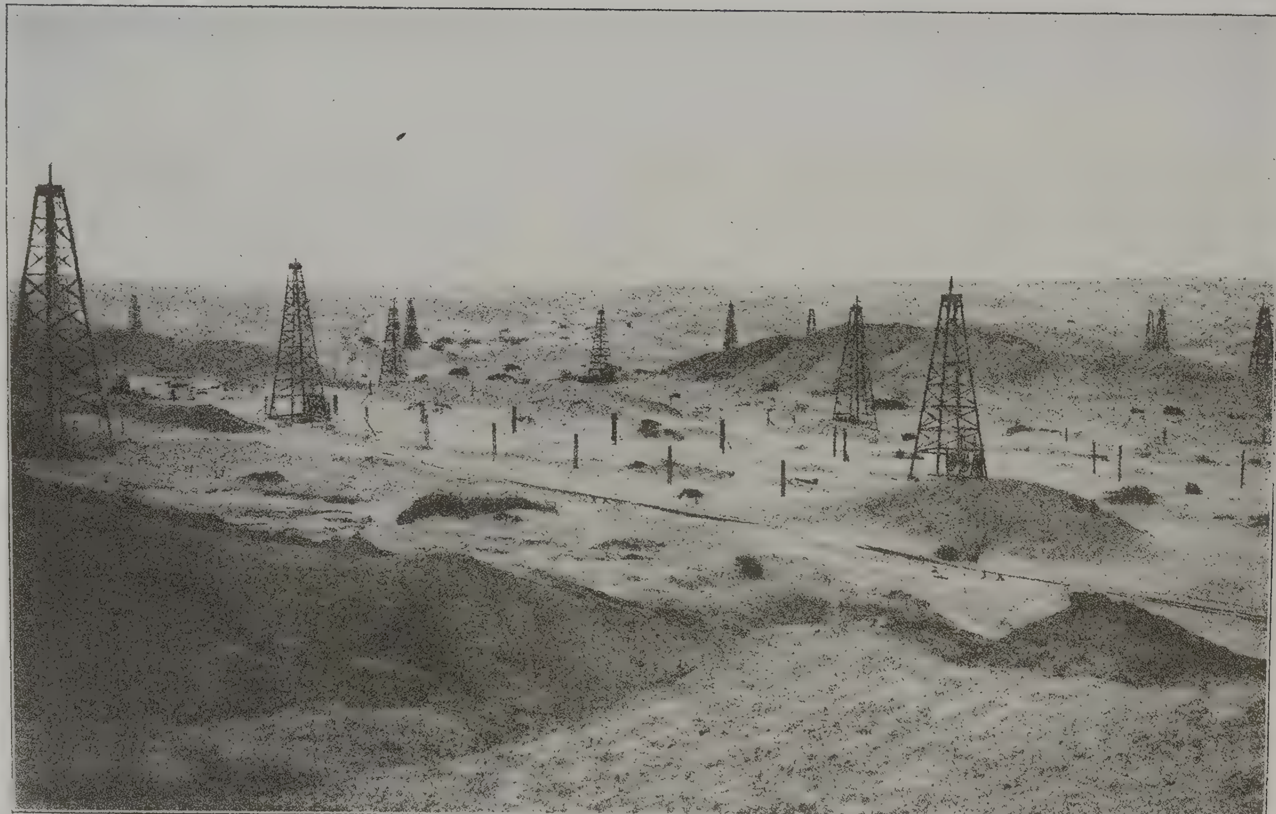
Towards the Parinas Sandstone some new fossils come in, occurring in seams of pebbly gritty sandstone, two or three feet thick.

A seam containing a large species of a smooth Melanatria-like shell, 6 inches in length, was found a short distance above the base (lat. ½, long. 2¾). Near the top there is a seam (lat. ¼, long. ¾), which contains a still larger species.

Approaching the Parinas Sandstone, there are passage beds of variable character, which include sandstones, grits, and pebble seams, in which occasionally many fossils occur. The assemblage of fossils is intermediate between that in the beds below and that in the sandstone group above. The several species which show progressive change are here of types very close to those of the Parinas Sandstone. *Clavilithes pacificus*, sp. nov., is plentiful, and *Morgania magna*, sp. nov., makes its first appearance in these beds.

(*e*) "THE PARINAS SANDSTONE" (1000 feet).

This member of the formation crops out in some seven fairly large fault-blocks (see Folder No. II.),



Photograph by T. O. Bosworth.

FIG. 9.—The Claylithes Series of the Negritos Formation. Viewed looking north-eastward from a point 1 mile E.N.E. of Negritos.

Photograph kindly lent by Mr. Beeby Thompson.

Fig. 10 The Parinas Sandstone, as seen in Quebrada Negritos, about 2 miles N. of Negritos.

This view shows the sandstone mass dipping eastward at 30°. The clay-shales in the foreground are the lowest beds of the Lobitos Formation, immediately overlying the Sandstone. At this place, however, there is some faulting at the contact.

and in several small ones, forming prominent hills. The total length of outcrop is about 10½ miles.

The deposit appears to be continuous throughout this district, but has not been identified with certainty in any other area. It forms the hill-mass of Punta Parinas; and the Mal Passo Hills (Fig. 10) and sea cliffs, 2 miles farther north, which continue for 3½ miles; also the Keswick Hills, a prominent ridge 3 miles in length, occurring 4 miles east of Punta Parinas; also the Yegua Blanca Hills, 3 miles south-east from Punta Parinas; and several smaller hills.

The Parinas Sandstone consists mainly of massive brown sandstone with beds of sandy shale and clay-shale. Some parts are conglomeratic and there are some bands of large pebbles. In the lower part there are generally one or more pebbly sandstone bands, with pebble beaches on them containing many fossils; but higher in the group the fossils are not numerous.

The fossil characteristic of these beds is *Clavilithes pacificus*, sp. nov. This shell, of which occasional smaller specimens were found in the lower members of the Clavilithes Series, is here abundant, and generally measures from 3½ to 5 inches.

Conspicuous also are *Pseudoliva parinasensis*, sp. nov., a large smooth *Morgania* (*M. magna*, sp. nov.), about 3 inches in length, *Sycum americanum*, sp. nov., and a small slender *Turritella*, of which the three last here occur for the first time.

There are also several small gasteropods with prominent varices. There appears to be a tendency for spiny species to be less spiny in these beds, or to be replaced by species which are smooth or have transverse ribs.

Of the gasteropods previously common, *Pseudoglauconia Lissoni* is notably abundant, in some cases forming special seams. *Turritella annectens*, sp. nov., *Volutospina peruviana*, sp. nov., and *Morgania costata*, sp. nov., are present but are further modified. *Surcula occidentalis*, sp. nov., *Clavilithes peruviana*, sp. nov. and *Pseudoliva mutabilis*, sp. nov., which became common in the Surcula Bed, are still plentiful; so also are *Strepsidura pacifica*, sp. nov., *Olivancillaria eocenica*, sp. nov., and larger specimens of the ribbed *Diastoma* (*D. americanum*, sp. nov.), *Melanatria acanthica*, sp. nov., and *Turritella Bosworthi*, sp. nov.

Among the pelecypods, the *Meretrix* and the inequivalve *Periploma*-like shell have disappeared. The *Venericardia* is less numerous, but is large and of a modified form. Oysters are not abundant, though several new species occur.

One of the features of this Parinas Sandstone is the driftwood (Fig. 11), which often occurs in profusion. These fossil logs are of all sizes up to 10 feet in length and 1 foot in diameter. The wood has nodes at regular intervals and is divided into segments. The logs lie horizontally and obviously are broken and drifted. Almost all are perforated by boring molluscs (*Teredina*), and usually contain many of their shells.

In certain fossil seams, this driftwood was found abundantly in company with the *Pseudoglauconia Lissoni*, *Volutospina*, and other shells.

In the more northern outcrops of the Parinas Sandstone (Mal Paso Hills), at the top of it where beds of gritty, pebbly sandstone alternate with beds of clay-shale, one or more thin seams were observed,

Photograph by A. H. Low.

A fossil tree-trunk, lying on a dip-slope of the Parinas Sandstone, from which it has been "weathered out."

consisting mainly of fossil wood and small fragments of coral (lat. 3, long. 2).

Thus the Parinas Sandstone is of marine deposition, and presumably was a large sand-shoal, formed at no great distance from the shore.

(2) NEGRITOS FORMATION IN THE LA BREA DISTRICT. (See Folder No. III., A.)

Twelve miles inland from Punta Parinas, the Negritos Formation appears in a group of low hills protruding from the surrounding Breccia Fan (lat. 3, long. 12).

These deposits are exposed to within 2 miles of the mountains, and accordingly are of a more littoral type than the corresponding deposits at Negritos. The fault-blocks dip in various directions, generally at 15°-20°.

Both the Turritella Series and the Clavilithes Series are present at La Brea, but the exposures of the former are of small extent.

TURRITELLA SERIES.

At the south-east corner of the mass, the uppermost 500 feet of the Turritella Series is well exposed. It consists of sandstones, clay-shales, and many pebble seams, with fossils in profusion. These include the *Venericardia planicosta*, the several *Turritellas*, and most of the familiar fossils of the Series. There is one special bed of *Turritella Lissoni*, sp. nov., and in most seams the *Turritella negritosensis* is present abundantly.

CLAVILITHES SERIES.

North-west of the Turritella beds, some thousands of feet of strata are seen which consist of clay-shales,

sandstone bands, pebble seams, and thick golden-brown sandstones and pebbly sandstones.

The lower part of this series contains many fossil seams in which the regular fossils of the Clavilithes Series are present in large numbers.

The Surcula Bed of the Negritos district was not recognised, and in one or two seams at the junction there was some admixture of *Turritella negritosensis*, sp. nov., with the *T. anceps*, which is proper to the series. One conspicuous seam, taken as the base of the series, is composed mainly of *Turritella Douvillei*, sp. nov.

Higher up in this series there is much sandstone, and the fossil seams are less numerous, but the *Pseudoglauconia Lissoni*, *Ostrea*, and *Venericardia* can generally be found, and often many other species also. One bed of sandstone, several feet thick, is largely composed of *Pseudoglauconia Lissoni*. (See Fig. 12.)

(3) NEGRITOS FORMATION IN THE MOGOLLON DISTRICT

About 15 miles inland from Talara there is an area of 40 square miles (lat. 10, long. 18), adjacent to the mountains, in which the Negritos Formation is exposed (Fig. 13). These outcrops would be continuous with those of the La Brea district, 5 miles south-west, if the overlying Breccia Fan were removed.

In this Mogollon district, the Turritella Series is not seen, for the Clavilithes beds have overlapped them on to the mountain flanks. The deposits are much faulted into many blocks, most of which are

Photograph by O. D. Boggs.

Fig. 13.—The Clavilithes Series of the Negritos Formation in the Mogollon district, 12 miles inland, 14 miles E.N.E. of Talara (about lat. 12, long. 16), looking seaward.

Skyline is formed by the Mancora Tablazo. In the centre of the picture, appearing almost white, the surface of an extensive terrace is seen. The present valley bed is some 30 to 50 feet below the terrace; its course is marked by the dark line of vegetation (Algarroba trees).

Photograph kindly lent by the Lobitos Oilfields Ltd.

FIG. 14.—The Negritos Formation, near Punta Restin, south of Cabo Blanco.

dipping towards the west at 10°-25°. (See Folder No. III., c.)

Going westward from the mountains we pass over the outcrops of some 5000-6000 feet of beds of the Clavilithes Series. In contact with the mountain rocks and resting on them, the shore-line deposits of the Clavilithes Series are well developed. They consist of a basal conglomerate, 50-100 feet thick, followed by about 600 feet of sandstones and conglomerates. Silicified wood is abundant in these sandstones, but no other fossils were found. The pebbles are of quartzite, slate, etc., derived entirely from the adjoining mountains. Often many of them are more than 6 inches in diameter.

East of these shore deposits we find a succession of sandstones and clay-shales containing abundant marine fossils. These beds are of shallow-water character, some of the sandstones being 100 feet thick, and the clay-shales containing much carbonaceous material and many pebble seams. The pebbles here are of the normal kinds.

The fossils are found in the pebble seams and are much the same as in the Negritos district, but it is noticeable that some species are thicker and less ornate, and some of the more delicate spiny gasteropods are absent.

After passing over 4000-5000 feet of these strata we find a sandstone group, more than 1000 feet thick, which may be equivalent to the Parinas Sandstone of the Negritos district. It consists of massive golden brown sandstones parted by beds of clay-shale containing plant remains. In some parts of the sandstone fossils are fairly common, but the number of

species is few. They are chiefly *Pseudoglauconia Lissoni*; a large smooth *Turritella*; a small, slender *Turritella*; *Mytilus euglyphus*, sp. nov.; *Venericardia planicosta*; and a strongly ribbed *Pteria*-like shell.

(4) NEGRITOS FORMATION AT JABONILLAL

Inland, north-east of Talara, about 7 miles (lat. 11, long. 9), denudation of the Quaternary cover has exposed some fault-blocks of the Negritos Formation to the extent of about 2 square miles. The beds belong to the Clavilithes Series, and contain the characteristic fossils. They consist of rather carbonaceous clay-shales and sandstones, as in the Mogollon district.

(5) NEGRITOS FORMATION IN THE CABO BLANCO DISTRICT

Four miles north of Lobitos, in the district of Punta Restin and Cabo Blanco, the Negritos Formation is brought up to the surface by block-faulting, and occupies the coast-line for a distance of some 12 miles (lat. 20 to lat. 32)

The strata exposed consist of clay-shales with pebble seams and beds of sandstone, one of which is 80 feet thick. (See Fig. 15 and Fig. 14.) They have the same appearance as at Negritos.

This district was only briefly inspected, but a number of fossils were collected, including the *Turritella anceps*, *Venericardia planicosta*, *Ampullina gabbi*, *Morgania magna*, *Melanatria* sp., *Clavilithes* sp., and *Volutospina peruviana*; from which it is concluded that these deposits belong to the Clavilithes Series.

Photograph lent by the Lobitos Oilfields Ltd.

Fig. 15.—The Negritos Formation, at Cabo Blanco.

This view of the cape is taken from the north side of it. The most northern producing well of the "Lobitos Oilfields" is seen on the left side of this picture. The strata are dipping seaward. Conspicuous among them is an 80 ft. bed of pinkish-white sandstone, which is the most prominent member of the formation in this district.

Photograph kindly lent by Mr. Beeby Thompson.

FIG. 16.—The Lobitos Formation, southern facies. Section seen in side of Quebrada Negritos, 2 miles north of Negritos.

CHAPTER VI

THE LOBITOS FORMATION OF THE TERTIARY

(1) LOBITOS FORMATION AROUND NEGRITOS AND THENCE SOUTHWARDS TO PAYTA

THIS formation occupies the surface in more than half of the area in which the Tertiary is exposed.

Owing to scarcity of fossils the details of the stratigraphy were not determined, but the total thickness appears to be at least 5000 feet.

In a north and south direction the exposures extend 65 miles, and in this distance the character of the deposits undergoes much lateral change. In almost all districts, however, occasional bands containing *Nummulites* or other discoidal *foraminifera* can be found.

The lower part of the formation is clearly exposed in the Negritos district, lying conformably over the Parinas Sandstone in most of the larger fault-blocks.

These lowest beds are well seen immediately east of the Keswick Hills (lat. -1 to $+2$, long. 4), 4 miles east of Punta Parinas, where the bare outcrops are visible for a length of 3 miles. They consist mainly of soft pale blue-grey clay-shales. (Fig. 16.)

In these first 500 feet or so of the Lobitos Formation there are occasional gritty sandstone bands, on which lie seams of beach pebbles containing a number

of fossils. These are chiefly species common in the Parinas Sandstone—notably *Pseudoglauconi Lissoni*, *Venericardia planicosta*, *Clavilithes pacificus*, sp. nov., *Turritella annectens*, sp. nov., *Pseudoliva parinasensis*, sp. nov., and also the fossil driftwood with boring molluscs. But along with these familiar fossils occur a few new ones, which connect the fauna with those of the thousands of feet of clay-shale which follows above.

Complete exposures of the basal beds are again seen, outcropping for a length of 4 miles, immediately east of the coastal ridge of Parinas Sandstone (lat. 2-6, long. 2). Here the clay-shales alternate with many beds of brown gritty sandstone, some of which are 20 feet thick and form prominent ridges. These sandstones are present, though in continually decreasing quantity, through at least 1000 feet of the Lobitos Formation in this neighbourhood. In some of these pebbly sandstones, fossils are fairly plentiful. Besides the species named above, they include a number of new gasteropods and generally a few discoidal *foraminifera* (*Nummulites*, etc.). Occasional streaks of sandstone are crowded with these *foraminifera*. They are found in some sandstones which are quite coarsely conglomeratic. (The occurrence of *Nummulites* in conglomerates is not infrequent, both in Peru and also in Ecuador.) These *foraminifera* are not found anywhere in the Parinas Sandstone nor in any of the beds below.

Proceeding eastward from the Negritos neighbourhood over the outcrops of many fault-blocks, it appears that we are ascending the formation. In these higher deposits sandstones become less numerous

Photograph by T. O. Bosworth.

Fig. 17.—The Lobitos Formation, about 6 miles inland from Punta Pariñas.

Photograph by T. H. Bosworth.

Fig. 18.—The Lobitos Formation, southern facies, a few miles east of Negritos.

and pebble seams are few or absent. The clay-shale is of fine texture and of paler tint than in the Negritos Formation (see Fig. 17 and Fig. 18), and seldom can any carbonaceous particles be seen in it. Some beds are somewhat calcareous and much selenite is formed in the weathering. Molluscan fossils are scarce or absent. In certain localities, however, there are seams of gritty sandstone, 3 or 4 feet thick, which have a "black and white" appearance due to the presence of many very small dark and white, angular pebbles. A few discoidal *foraminifera*, shark's teeth and small gasteropods are present on, and in, these beds.

Several important beds of this sand, 6-10 feet thick, occur east of Lagunitas (lat. 0, long. 5) and are overspread with beach pebbles and many fossils. At this locality the fossil seams are rather similar to those in the Negritos Formation. Almost all of the species, however, are different. They include, *Faunus lagunitensis*, sp. nov., *Tympanotonus lagunitensis*, sp. nov., *Telescopium peruvianus*, sp. nov., etc.

The foregoing observations relate to the Lobitos Formation in the middle of the map (lat. -5 to $+5$).

To the southward the clay-shale development of the Lobitos Formation is maintained, covering a large area in the south part of the map. Throughout much of this territory sandstone and pebbles are rather scarce, and fossils are rarely seen. Approaching the Rio Chira, however, about latitude -10 to -15, bands of sandstone and brown conglomerate composed of very small rounded pebbles, sometimes 10 to 20 feet thick, become frequent. In these there are some large long oysters and fragments of other shells.

Inland, about 7 miles N.N.E. of Amotape, around lat. –7, long. 25, a considerable development of sandstone and conglomerate is exposed. As the mountains are only 4 miles distant, there is possibly a coastal facies here; but the intervening space is covered by the Breccia Fan.

From the Rio Chira southward to Payta, the country is covered by the Quaternary deposit, and the Lobitos Formation beneath it is revealed only along the cliffs. The rocks seen, consist almost wholly of clay-shale, but they have not been much examined.

In three localities in the southern part of our area the monotonous barren condition of the Lobitos Formation is not maintained. In each of these places, richly fossiliferous beds are exposed which may be due to coastal conditions, or to lower beds of the formation having been brought up by the block-faulting. At first it was supposed that these were masses of the Negritos Formation, but closer study of the fossils indicates that they are probably of Lobitos age. Although a number of the species are those common in the Negritos Formation, they have undergone modification here; and it is notable also that the several characteristic *Turritellas* of the Negritos Formation do not occur.

These localities, in order from north to south, are as follows:

Near Gaguay Grande.—Here there is a small exposure, 30 miles inland from Punta Parinas, against the south flank of the mountains (lat. 2, long. 30). The beds consist of clay-shale and sandstone. The fossils include some rather large pelecypods.

Photograph by A. H. Low.

Fig. 19.—Faults in the Lobitos Formation, Parinas District. Seen in the wall of a Quebrada which is tributary to Quebrada Parinas.

Photograph by E. G. Simmons.

FIG. 20. In the distance we see the rocks of Talara Point bearing a lighthouse on their summit, and the Refinery of the International Petroleum Co. at their foot. In the far background is the Pacific Ocean, with Talara Bay to the right of Talara Point. A sandy plain, only a few feet above sea level, occupies the middle of the view. This plain has been abandoned by the sea in geologically recent times (see Part III.). During the floods of 1891 it was again occupied by water (see Part IV.).

The rocks of Talara Point are composed of calcareous sandstones and shales of the Lobitos Formation. The observer is looking obliquely at their dip-slope. In the right foreground, similar beds are well seen, though here dipping in a different direction. They are capped by the horizontal Tablazo bed, 250 feet.

Ten miles W.N.W. of Sullana.—Here, north of the Rio Chira, about 20 miles inland (lat. −12, long. 35), the fossiliferous strata are exposed over an area exceeding 50 square miles—which was only partially inspected. The deposit consists of clay-shales with pebble seams and beds of sandstone, dipping north-west at 5°-10°. Fossils are abundant, and include, *Venericardia planicosta*; *Scapharca* (*Argina*) *sullanensis*, sp. nov.; *Perna arbolensis* (?), sp. nov.; *Dientomochilus* (*Ectinochilus*), sp. cf. *laqueata* (Conr.); *Volutospina peruviana*; *Pseudoliva parinasensis* (large form); *Conus* (*Lithoconus*) sp.

At Payta.—In the south-west corner of the map (lat. −29, long. 14), there is a small exposure of fossiliferous beds in the cliffs immediately west of Payta. Here under a cover of Quaternary, the clay-shales, sandstones, and pebble seams are found in contact with small masses of the mountain rocks. The fossils include, *Ampullina paytensis*, sp. nov.; *Cerithium paytensis*, sp. nov.; *Lucina paytensis*, sp. nov.; and *Callianassa*.

(2) LOBITOS FORMATION NORTH OF THE NEGRITOS DISTRICT, AND AROUND LOBITOS

Traced northward from the neighbourhood of Negritos and Lagunitas, the Lobitos Formation undergoes an interesting change in character, and at length becomes a series of alternating clay-shales and yellowish calcareous sandstones. (Fig. 21.)

In these beds a few discoidal *foraminifera* can often be found, and occasional seams are crowded with them; but other fossils are rare or absent.

The sandstone bands become numerous a mile or

two north-east from Negritos (lat. 2); and north of Talara (lat. 7), they constitute a large proportion of the formation. Here the thickness of the bands varies from a few inches up to 10 or 15 feet. As we proceed farther northward, to Lobitos (lat. +16), thicker beds become frequent and are well seen in cliffs and in many ridges. North of Lobitos an interesting bed was found containing many specimens of a large *Nautilus* (?).

Inland from Lobitos this facies of the formation is extensively exposed up the Quebrada Honda and near the mountains. At some places there are beds of " nummulite " sandstone, 50-100 feet thick.

As the mountains are approached, micaceous sandstone and grit (with discoidal *foraminifera*), becomes an important ingredient in the deposit; and adjacent to the shore-line there are coastal conglomerates and basal breccias. In these the pebbles are of slate, quartzite, granite, etc., derived from the Amotape Mountains; wherein they differ entirely from the pebbles found in the pebble beds of the Negritos neighbourhood.

(3) LOBITOS FORMATION NEAR PUNTA ORGANO

North of Cabo Blanco, about lat. 32, the Lobitos Formation is again exposed, and continues along the coast for several miles. In this district the geology was not mapped, but the formation was seen to consist of clay-shales with calcareous sandstones, and one or more beds of coarse conglomerate.

The curious hill, Mount Organo (575 feet), which

Photograph by A. H. Low.

FIG. 21.—A typical view of the northern facies of the Lobitos Formation. Bands of calcareous sandstone alternating with bands of clay-shale. The sandstones contain Nummulites and discoidal foraminifera. Parinas Valley, 4 miles N.E. of Talara.

Photograph kindly lent by The Lobitos Oilfields, Ltd.

FIG. 22. The Lobitos Formation, in the Lobitos Oilfield. The beds consist of clay-shales, with bands of calcareous sandstone. In the distance the strata are seen to be dipping towards the right background at an angle of 10°-20°.

This picture also illustrates the usual arrangement for pumping the wells in these fields. Near the centre of the view is a shed containing an engine which is connected up with a number of wells.

has columnar cliffs resembling organ pipes, is capped by a seam containing discoidal *foraminifera*. Punta Organo Chico also, is formed by a thick bed of sandstone crowded with these *foraminifera*, and underlain by conglomerate.

CHAPTER VII

THE ZORRITOS FORMATION OF THE TERTIARY

THE northern part of the region, from Mancora to Tumbes, was traversed often, but little of it was examined in detail.

The Tertiary is exposed all along this coast, generally in cliffs capped by Quaternary marine terraces and beaches. But no beds were observed which could bc correlated with anything in the Lobitos and Negritos formations to the south; and the numerous fossils which were found in many places, appeared to belong to higher horizons. The beds exposed were estimated to have a thickness of at least 5000 feet, and probably considerably more.

Around Zorritos (lat. 70), the deposits exposed and proved by borings, consist of:

(2) *Sandy Series.*[1]—Thickness—several hundred feet. Irregular brown sandstones and conglomerates, with some beds of shale between, passing down into the series below. Many fossils.

(1) *Clay-shale Series.*—Thickness—several thousand feet. Almost entirely clay-shales.

Along the coast, the Sandy Series is seen more

[1] Some of the fossils described by J. Grzybowski (*loc. cit.*) were from these beds. Miocene fossil plants collected from a lignitic seam probably in this series, have been described by Professor E. W. Berry (*Proc. U.S. Nat. Museum*, vol. lv. p. 179).

Photograph kindly lent by Mr. Beeby Thompson

FIG. 23.—The Clay-shales of the Zorritos Formation, as seen in Quebrada Heath, near its mouth. North of Zorritos.

Photograph kindly lent by Mr. Beeby Thompson.

FIG. 24.—The Sandstone in the upper part of the Zorritos Formation, as seen in Quebrada Heath, north of Zorritos.

or less continuously for 20 miles. The dips in this district are lower than usual (5°-15°), and the faulting is less severe.

A few miles inland from Zorritos, in a group of hills which protrude high above the Tablazo level, the same series are recognised and the same fossils are found.

Along the coast between lat. 51 and lat. 56, some strata of different appearance were observed. It is not certain that they belong to this formation.

Many fossils were found in the Sandy Series at Zorritos, Caleta Grau, Quebrada Heath, Boca Pan, and in the hills inland. They include *Balanus*; several species of *Turritella; Conus; Solarium; Scapharca; Crassatellites;* etc., etc. All are different from those in the Negritos and Lobitos formations. They are considered to be of Miocene age.

CHAPTER VIII

CONCLUSIONS

(1) In north-west Peru, which is the most westerly part of South America, the narrow strip of country between the mountains and the sea is occupied by Tertiary rocks.

(2) The Tertiary beds are exposed at the surface in about a quarter of this area, and in the remaining three-quarters they lie beneath a thin cover of almost horizontal Quaternary strata.

(3) The shore-line of the Tertiary sea lay against the western slope of the outer range of the Andes, which is a pre-Tertiary range.

(4) The Tertiary is divisible into three formations:

Miocene	c. *Zorritos Formation* . . Fauna rich in gasteropods. All species different from those below.	5000 feet +
Eocene	b. *Lobitos Formation* . . . Contains discoidal foraminifera.	5000 feet +
	a. *Negritos Formation* . . Fauna rich in gasteropods .	7000 feet +

(5) The Tertiary contains a large molluscan fauna. Most of the species are new.

The Eocene age of the two lower formations is indicated by the presence of *Venericardia planicosta*

and several other species similar to those in the Californian and Gulf Coast Eocene, also by the occurrence of *Aturia* and certain discoidal *foraminifera*, and by the corals.

The Miocene age of the highest formation is deduced from study of the barnacles, and also from the similarity of some of the gasteropods and pelecypods to those in the Miocene of Panama.

(6) The Tertiary is of great thickness. Thus at a distance of 12-14 miles from the shore-line of the deposit, 8000 feet of strata, lying bed upon bed, are fully exposed by the elaborate block-faulting within a radius of one mile; and beneath these an additional 1500 feet is proved by borings. All of this is in the Negritos Formation and in the lower part of the Lobitos Formation.

Possibly the Zorritos Formation lies unconformably over the Lobitos and Negritos Formations; but it is not improbable that in some parts of the area the actual depth of the Tertiary accumulation attains to 20,000 feet.

(7) The Tertiary is wholly of shallow-water origin, consisting mainly of clay-shales and sandstones. Throughout a large part of it there are innumerable thin seams of beach pebbles and shells. It was deposited in lagoons and shallow sea, on the continental shelf, not very far from the mouth of some large river.

(8) There was continual subsidence of the sea-floor on which the Tertiary was being accumulated. These subsidences, which occurred at very frequent intervals, compensated for the gradual silting up, and altogether must have amounted to 10,000-20,000 feet or more.

(9) There is no folding in the Tertiary, but the earth's crust is so intensely broken up by faulting as to resemble a giant crush-breccia. The faults have all directions and radiate from many points. The fault-blocks are inclined in many different directions, at angles of 5°-35°. Where they lie against the mountains, the blocks are tilted westward, and the mountain rocks beneath them participate in the faulting. The block-faulting, visible in the Tertiary beds of the Littoral, expresses the block-faulting of underlying mountain rocks.

(10) These disturbances were part of the earth movement, by which the Andes mass was being further uplifted, whilst the ocean floor was being depressed. Thus after the deposition of the Tertiary beds on a subsiding floor, there was an accentuation of the great movement and the mountains received an uplift.

In this process the continental shelf was block-faulted, and parts of the Tertiary accumulation, most adjacent to the mountain flanks, were lifted above water, forming a zone of dry land 10-20 miles wide, which is the Littoral.

The Littoral is part of the crush-belt of this geo-fault. The axis lies in the Pacific, along the edge of the continental shelf.

(11) The Tertiary deposits suffered deep denudation, during and after their block-faulting and emergence from the sea.

Subsequently, remarkable oscillatory movements of the Littoral have been in progress, which have enabled the Quaternary Sea to carve out extensive planes of marine erosion, on which thin marine deposits have been laid. The net results of these later move-

ments, however, has been a further uplift of 200-1200 feet. (These movements and their effects are described in detail in Part III.)

The Tertiary is now exposed wherever the Quaternary cover has been eroded away.

(12) The thickness of the Eocene and Miocene deposits, the depth of the contemporaneous subsidences, the height of the subsequent block-faulting, and the amount of denudation which preceded the Quaternary marine erosion and deposition, bear witness to the vastness of geological time.

PART II

PALÆONTOLOGY OF THE TERTIARY DEPOSITS

By Henry Woods, M.A., F.R.S., T. Wayland Vaughan, Ph.D., J. A. Cushman, Ph.D., and H. L. Hawkins, D.Sc.

E

SECTION A

MOLLUSCA FROM THE EOCENE AND MIOCENE DEPOSITS OF PERU

By Henry Woods, M.A., F.R.S.

CHAPTER I

GENERAL ACCOUNT OF THE FAUNAS AND THEIR RELATIONSHIP

With the exception of a small number of species of Mollusca, mainly of Miocene and Quaternary age, described by W. M. Gabb,[1] E. T. Nelson,[2] and J. Grzybowski,[3] nothing seems to have been written on the Palæontology of the Tertiary deposits of Peru.[4] The discovery of a rich Eocene fauna in this region is of considerable interest on account of the limited development of Eocene formations in the Southern Hemisphere.

[1] "Descriptions of New Species of South American Fossils.—No. 1, Tertiary," *American Journ. Conch.* v. (1870), p. 25; figures published in *Journ. Acad. Nat. Sci. Philadelphia* (8), II. (1877), p. 264, Pl. xxxv.

[2] "On the Molluscan Fauna of the Later Tertiary of Peru," *Trans. Connecticut Acad. Arts and Sci.* II. Pt. 1 (1870), p. 186, Pls. vi., vii.

[3] "Die Tertiarablagerungen des nordlichen Peru und ihre Molluskenfauna," *Neues Jahrb. für Min.* etc., Beil.-Bd. XII. (1899), p. 610.

[4] A brief account of the Eocene of Peru has recently been published by Prof. H. Douvillé, *Compte Rendu Acad. Sci.* clxxi. (1920), p. 1345, and *Compte Rendu somm. Soc. géol. France*, No. 14 (1921), p. 193.

For help in comparing some of the Mollusca with recent and fossil specimens in the British Museum (Nat. Hist.) I am indebted to Mr. G. C. Robson and Mr. R. Bullen Newton. The late Mr. G. C. Crick kindly examined the specimens of *Aturia.* I must also thank Mr. C. P. Chatwin for giving me his opinion on the affinities of some of the Gasteropods. Mr. T. H. Withers has been good enough to report on the two Cirripedes found in the Zorritos Formation.

The deposits under consideration are divided into three main groups termed (1) the Negritos Formation, (2) the Lobitos Formation, (3) the Zorritos Formation.

1. The Negritos Formation

The fauna of the Negritos Formation is of shallow-water character, and consists mainly of Gasteropods and Lamellibranchs, with a small number of Fish teeth, Decapod Crustacea, and Corals. Cephalopods are represented by a species of *Aturia.* No remains of Brachiopods, or Cirripedia have yet been found. The Mollusca are, in general, well preserved, but unfortunately the apertures of the Gasteropods are often imperfect, and owing to weathering in an arid region, the ornamentation of the early part of the spire is often indistinct or obliterated; so that exact generic determination is not infrequently difficult.

Some of the species of Mollusca, which range through the greater part of the Negritos Formation, are of interest in that they show a gradual change of characters, when traced through successive horizons, the change consisting mainly in the increase of senile

features. Thus the group of *Venericardia planicosta* starts with forms in which the ribs are well developed throughout life, and is succeeded in later beds by others in which they become obsolete near the ventral margin, and eventually are wanting over a large part of the shell.

In *Volutospina peruviana*, sp. n., the callus shows progressive development in passing from early to later beds, until ultimately it covers the entire shell. Similarly *Pseudoliva mutabilis*, sp. n., and *Strepsidura pacifica*, sp. n., exhibit an increase in the development of senile features.

A considerable proportion of the species occur in both divisions of the Negritos Formation; but the earlier division, the Turritella Series, in addition to the zonal forms of *Venericardia planicosta*, *Volutospina peruviana*, sp. n., and of *Pseudoliva mutabilis*, sp. n., is characterised by *Turritella negritosensis*, sp. n., *T. Lissoni*, sp. n., *T. Douvillei*, sp. n., *Melanatria dimorphica*, sp. n., *M. propinqua*, sp. n., *Bezanconia pupoidea*, sp. n., *Cerithium Chatwini*, sp. n., *Volutospina crassiuscula*, sp. n., *Ostrea Buski*, sp. n. Of these, *Turritella negritosensis* is especially abundant and shows much variation.

The newer division, the Clavilithes Series, with the Parinas Sandstone at the top, in addition to the zonal forms of *Venericardia planicosta*, *Volutospina peruviana*, and *Pseudoliva mutabilis*, is distinguished especially by the presence of *Clavilithes*, represented by four species, and by *Turritella anceps*, sp. n., *Morgania magna*, sp. n., *Melanatria acanthica*, sp. n., *M. venusta*, sp. n., *Cerithium negritosense*, sp. n., *Diastoma americanum*, sp. n., *Sycum americanum*, sp. n., *Surcula*

Thompsoni, sp. n., and *Callista* (*Macrocallista*) *Dickersoni*, sp. n. Of these species *Turritella anceps* is particularly abundant. Forms confined to the Parinas Sandstone are *Corbula parinasensis* and *Sycum americanum.*

There appear to be no marine deposits of similar age yet described in South America,[1] but comparison of the fauna of the Negritos Formation can be made with the Eocene faunas of (1) the Pacific coastal region of the United States, and (2) the Eastern and Gulf States.

The stages reached in the evolution of the *Venericardia planicosta* group indicate that the Negritos Formation is represented by the Tejon Group and part of the Meganos Group[2] of California. But although many of the other genera of Mollusca are common to the two regions, the resemblances between the species are few and not striking.

The relation to the faunas of the Eastern and Gulf States of America is more marked, and the stages of development reached by the *Venericardia planicosta* group indicate that the Negritos Formation is represented by the Wilcox and Lower Claiborne Groups. The Claiborne Group is probably of Lutetian and Auversian age, and represented by the Bracklesham Beds of England; the Wilcox Group may be in part of Ypresian age. Although scarcely any of the other species of Mollusca are common to the two regions this correlation receives support from the resemblances between some of the species found in

[1] Dr. Bosworth states that Eocene deposits occupy a considerable area in Ecuador, and probably also in Colombia and Venezuela.

[2] B. L. Clark, *Bull. Geol. Soc. America*, xxix. (1918), p. 281.

the two areas. The principal forms in the Negritos Formation which are comparable with species found in the Wilcox and Lower Claiborne Groups are *Solarium Nelsoni*, sp. n., *Turritella negritosensis*, sp. n., *Dientomochilus* (*Ectinochilus*) sp. cf. *laqueata* (Conr.), *Pseudoliva parinasensis*, sp. n., *Clavilithes Harrisi*, sp. n., *C. peruvianus*, sp. n., *Volutospina peruviana*, sp. n., and *Ostrea Inca*, sp. n. The differences between the faunas of the two regions are, however, very striking; in addition to almost complete differences in species, a number of genera which are abundant in the Wilcox and Claiborne Groups are unknown in the Negritos Formation of Peru; as, for example, *Olivula*, *Bullinella* (*Cyclichna*), *Caricella*, *Lacinia*, *Buccinanops*, *Crassatellites*, *Pectunculus*, and *Grateloupia*; on the other hand the genera *Morgania*, *Melanatria*, *Bezanconia*, *Sycum*, and *Xanthopsis* appear to be unknown in the Wilcox and Claiborne Groups. The resemblances between the faunas are sufficient to indicate the existence of a sea connection between the Pacific and the Atlantic; the dissimilarities in the faunas point to a difference in climate, and probably also to the want of any direct shallow-water connection between the two regions. Evidence for inter-oceanic communication across Central America in Upper, and probably Middle Eocene, and later times has been furnished by the study of the Tertiary faunas of the West Indies and the Panama region,[1] as well as from the distribution of Tertiary Mammals.

[1] T. W. Vaughan, *U.S. National Mus. Bull.* 103 (1919), pp. 198, 207, 211, 221, 607, and table, p. 611; and *Bull. Geol. Soc. America*, xxix. (1918), p. 615. R. E. Dickerson, "Ancient Panama Canals," *Proc. California Acad. Sci.* (4), vii. (1917), p. 197.

Eocene deposits with *Venericardia planicosta* have been found near Tonosi, Panama, but unfortunately no other fossils have been recorded. In the West Indian Islands deposits of this age appear to be known only at Soldrodo Rock, Trinidad, where *V. planicosta* has been found.

There are some forms found in the Negritos Formation which resemble species present in the Lutetian and Auversian of France and England, such as species of *Clavilithes*, *Strepsidura*, *Sycum*, *Venericardia*, and *Xanthopsis*. Other species show some resemblance to forms found in the Alpine Middle Eocene, especially to those from Vicenza and Verona (N. Italy); these forms are *Volutospina crassiuscula*, sp. n., *Melanatria dimorphica*, sp. n., *M. venusta*, sp. n., *Bezanconia pupoidea*, sp. n., *Cerithium negritosense*, sp. n., and *Diastoma americanum*, sp. n. Also *Pseudoliva mutabilis*, sp. n., is similar to a species in the Eocene of Algiers. Taken collectively, these resemblances seem to be of significance in connection with the relationship noticed, by various writers,[1] between the Tertiary faunas of the West Indies and the Mediterranean region. The two elements in the Negritos fauna—(1) resembling the Eocene of the Eastern and Gulf States of America and Western Europe, and (2) resembling the Eocene of Southern Europe—would be explicable on the assumption of a Transatlantic Ocean with a northern and southern shore-line.[2]

[1] See, for example, P. M. Duncan, *Quart. Journ. Geol. Soc.* xxiv. (1868), pp. 26-33; J. W. Gregory, *ibid.* li. (1895), pp. 306-309. Revised names of the corals are given by T. W. Vaughan, *U.S. Nat. Mus. Bull.* 103 (1919), pp. 228-287 and in the systematic descriptions following.

[2] E. Haug, *Traité de Géologie*, ii. (1908–11), pp. 1525, 1560, and Map Fig. 431.

2. The Lobitos Formation

The fossils in the Lobitos Formation are less abundant and not so well preserved as those in the Negritos Formation, and it has not been possible to determine the species in all cases. The greater part of the fossils examined were collected from the lowest 1000 feet of the formation, east of Negritos. These, and the specimens from the Payta and Sullana districts, show a close connection with the Clavilithes Series of the Negritos Formation. Nearly all these species are either the same as or only slightly different from those found in the Clavilithes Series, and indicate correlation with a part of the Claiborne Group. *Venericardia planicosta* although uncommon is still represented. *Volutospina peruviana*, sp. n., of the type which occurs in the Parinas Sandstone, is present. Other species which connect the Lobitos Formation with the Negritos Formation are *Turritella annectens*, sp. n., *Strepsidura pacifica*, sp. n., *Clavilithes pacificus*, sp. n., *C. Harrisi?*, *C. incertus?*, *Volutospina meridionalis*, sp. n., *Morgania magna?*, *Pseudoliva parinasensis*, sp. n., *Callianassa americana*, sp. n. Part of an unstalked Crinoid has been found in the Lobitos Formation.

At Lagunitas, the horizon of which is believed to be considerably higher, the species are mainly different from those of the Negritos Formation. *Nassa lagunitensis*, sp. n., is found here and probably also in the lower beds of the Lobitos Formation. *Strepsidura* is represented by small weathered specimens which may belong to *S. pacifica*. Species which are confined to

this horizon are *Telescopium peruvianum*, sp. n., *Faunus? lagunitensis*, sp. n., *Tympanotonus lagunitensis*, sp. n., *Olivancillaria* (*Agaronia*) *peruviana*, sp. n. These differences in the fauna at Lagunitas are due, in part, at any rate, to a difference in the conditions of deposition.

3. The Zorritos Formation

The fossils of the Zorritos Formation include, amongst others, *Solarium sexlineare*, Nels., *Turritella infracarinata*, Grzyb., *T. robusta*, Grzyb., *T. gothica*, Grzyb., *T.* sp. cf. *altilira*, Conrad, *Conus* sp., *Scapharca zorritosensis*, sp. n., *Crassatellites charanensis*, sp. n., *Clementia* sp. cf. *dariena*, Conr., *Balanus* sp. cf. *concavus*, Bronn. The Zorritos Formation has been regarded by Grzybowski and other writers as of Miocene Age, and this view is supported by the presence of *Turritella* sp. cf. *altilira*, *Clementia* sp. cf. *dariena*, and *Crassatellites charanensis*, sp. n. *Balanus* is represented by two specimens; these have been examined by Mr. T. H. Withers, who states that they may be provisionally identified with *B. concavus*, Bronn, and that they are probably of Miocene Age, and certainly not Eocene.[1]

[1] An account of the Miocene Plants of Peru is given by E. W. Berry, *Proc. U.S. Nat. Mus.* lv. (1919), p. 279. See also *Bull. Geol. Soc. America*, xxix. (1918), p. 637.

TABLE SHOWING RANGE OF MOLLUSCA AND CRUSTACEA IN THE NEGRITOS AND LOBITOS FORMATIONS

	Negritos Formation.			Lobitos Formation (between Talara and Payta).		
	Turritella Series.	Clavilithes Series				
	Shales with Pebble Seams.	Shales with Pebble Seams.	Parinas Sandstone.	Lowest 1000 feet around Negritos.	Horizons exposed at Payta and W.N.W. of Sullana.	Horizon exposed near Lagunitas, and higher beds.
LAMELLIBRANCHIA						
Leda ingens, sp. n.	q	p				
Barbatia, sp.	o					
Scapharca (Argina) sullanensis, sp. n.					p	
Mytilus euglyphus, sp. n.	p (?)	p	p (?)			
Ostrea Inca, sp. n.	q	p				
„ *Buski*, sp. n.	q	q				
Perna arbolensis, sp. n.			o		(?)	
Venericardia planicosta, Lam. (group)	p	p	p	p	o	
Lucina paytensis, sp. n.					p	
Callista (Macrocallista) Dickersoni, sp. n.		o				
Meretrix Bosworthi, sp. n.	p	q				
„ *negritosensis*, sp. n.	o	q				
Cardium, sp.	o					
Corbula peruviana, sp. n.	p	o				
„ *Waringi*, sp. n.	p	o				
„ *Arnoldi*, sp. n.	o					
„ *parinasensis*, sp. n.			p			
Teredina, sp.	p	p	p	o		
GASTEROPODA						
Solarium Nelsoni, sp. n.	p	p	p			
Natica (Naticina), sp.				o		
Ampullina Gabbi, sp. n.		o				
„ *paytensis*, sp. n.					p	
Turritella negritosensis, sp. n.	q					
„ *Dickersoni*, sp. n.	p	p	p (?)			
„ *Bosworthi*, sp. n.		p	p			
„ *Douvillei*, sp. n.	q					
„ *Lissoni*, sp. n.	q					
„ *anceps*, sp. n.		q				
„ *annectens*, sp. n.		q	q	p		
Morgania magna, sp. n.		(?)	p	(?)		
„ *costata*, sp. n.	q	q	q			
Melanatria dimorphica, sp. n.	p					
„ *acanthica*, sp. n.		q	p			
„ *propinqua*, sp. n.	p					
„ *venusta*, sp. n.		o				
Pseudoglauconia Lissoni, Douv.	p	q	q	o (?)		
Faunus ? lagunitensis, sp. n.						p
Cerithium paytense, sp. n.					p	p
„ *negritosense*, sp. n.		p				
„ *Chatwini*, sp. n.	q					
Bezanconia pupoidea, sp. n.	p					
Potamides occidentalis, sp. n.	o (?)	p				p
Tympanotonus lagunitensis, sp. n.				p	(?)	p
Telescopium peruvianum, sp. n.						
Diastoma americanum, sp. n.		o				

EXPLANATION

o denotes fossil was found occasionally.
p „ „ „ „ plentifully.
q „ „ „ „ in quantities.

TABLE SHOWING RANGE OF MOLLUSCA AND CRUSTACEA IN THE NEGRITOS AND LOBITOS FORMATIONS—*continued.*

	NEGRITOS FORMATION			LOBITOS FORMATION (between Talara and Payta)		
	Turritella Series.	Clavilithes Series.				
	Shales with Pebble Seams.	Shales with Pebble Seams.	Parinas Sandstone.	Lowest 1000 feet around Negritos.	Horizons exposed at Payta and W.N.W. of Sullana.	Horizon exposed near Lagunitas, and higher beds.
GASTEROPODA—*continued*						
Calyptrophorus (*Aulacodiscus*) *Lissoni*, Douvillé		o				
Dientomochilus (*Ectinochilus*) sp. cf. *laqueata* (Conr.)					p	
Pseudoliva parinasensis, sp. n.	o	o	p	p	p	
,, *mutabilis*, sp. n.	p	p	p			
Nassa lagunitensis, sp. n.					(?)	p
Strepsidura pacifica, sp. n.	p	q	p	p		(?)
Clavilithes Harrisi, sp. n.		o		(?)		(?)
,, *peruvianus*, sp. n.	?	q	p	o		
,, *pacificus*, sp. n.		p	q	p		
,, *incertus*, sp. n.		p	o	(?)		
Sycum americanum, sp. n.			p			
Volutospina peruviana, sp. n.	p	q	p	o	p	
,, *crassiuscula*, sp. n.	p					
,, *meridionalis*, sp. n.		o		p		
Olivancillaria eocenica, sp. n.	p	q	p			
,, (*Agaronia*) *peruviana*, sp. n.					(?)	p
Surcula occidentalis, sp. n.	o	q	p			
,, *Thompsoni*, sp. n.		p				
Conus (*Lithoconus*), sp.					p	
CEPHALOPODA						
Aturia, sp.	p	p				
CRUSTACEA						
Callianassa parinasensis, sp. n.				p		
,, *americana*, sp. n.	q	q				
Xanthopsis errans, sp. n.		q				
Thaumastoplax eocenica, sp. n.		o				

EXPLANATION

o denotes fossil was found occasionally.
p ,, ,, ,, ,, plentifully.
q ,, ,, ,, ,, in quantities.

CHAPTER II

DESCRIPTION OF THE LAMELLIBRANCHIA FROM THE NEGRITOS AND LOBITOS FORMATIONS

FAMILY LEDIDÆ

Genus LEDA, Schumacher.

Leda ingens, sp. n.

Plate I., Figs. 1-3.

Description.—Shell inflated; length a little less than twice the height. Umbones nearly median, turned posteriorly. Behind the umbones is an elongate-ovate depressed area, without ornamentation. Anterior margin of valves rounded, passing gradually into the convex ventral margin which makes a small sinuosity where it joins the posterior (or rostral) prolongation; this prolongation is relatively short, compressed, and with the posterior margin vertically truncated.

The ornamentation consists of strong concentric ribs which make an obtuse angle with the nearly vertical ribs of the rostral prolongation; the ribs on that part are narrower, sharper, and less numerous than those on the flanks.

Remarks.—This species shows some resemblance to *Leda alœformis* (Gabb) [1] from the Martinez Group of California,[2] but the shell is relatively less elongate, the rostral part is less produced, the convexity of the ventral border (and the concentric ribs) is continued farther back so that the postero-

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[1] *Geol. Surv. California Palæont.* vol. ii. (1869), p. 177, Pl. XXIX. Fig. 63. T. W. Stanton, "Faunal Rel. of Eoc. and U. Cret. Pacific Coast," *17th Ann. Rep. U.S. Geol. Surv.* (1896), p. 1040, Pl. LXIV. Figs. 6, 7. C. A. Waring, *Proc. California Acad. Sci.* (4), vii. (1917), p. 76, Pl. XII. Fig. 12.

[2] For distribution, see R. E. Dickerson, "Fauna of Martinez Eocene," *Univ. Calif. Publ. Bull. Geol.* viii. (1914), p. 107.

ventral sinuosity is less broad and the ribs at the anterior end have a more marked upward curvature.

This species, like *L. alæformis*, is remarkably large. The character of the hinge is seen in an internal cast.

Distribution.—Turritella Series, around Negritos, La Brea, etc.; also in the Clavilithes Series, but less numerous.

Family ARCIDÆ

Genus Barbatia, Gray.

Barbatia, sp.

Plate I., Fig. 4.

There is a single imperfect specimen of *Barbatia* in which the shell is ornamented with faint radial ribs: an inconspicuous carina extends from the umbo to the postero-ventral extremity; the flanks and the ventral margin are slightly concave.

From the Turritella Series, 1 mile east of Negritos.

Genus Scapharca, Gray.

Section Argina, Gray.

Scapharca (*Argina*) *sullanensis*, sp. n.

Plate I., Fig. 5.

Description.—Shell inflated, subcordiform, equivalve, inequilateral, length and height nearly equal, postero-dorsal surface compressed. Anterior margin subtruncate; posterior margin oblique; ventral margin convex. Umbones broad, curved forwards and inwards. Area behind the umbones narrow, deeply sunk; in front of the umbones cordate, shallow, faintly limited. Shell ornamented with numerous broad flattened ribs with flat interspaces, both crossed by numerous concentric growth-lines. Hinge not seen, but the weathered surface of the area shows evidence of numerous small teeth.

Remarks.—Only one specimen has been seen. A species of *Argina* (*A. tolepia*, Dall) [1] is found in the Oligocene of Florida but is clearly distinct from this species.

[1] "Tertiary Fauna of Florida," Pt. IV. *Trans. Wagner Free Instit. Science*, vol. iii. (1898), p. 649, Pl. xxxiii. Figs. 7, 8.

Distribution.—Lobitos Formation, 10 miles W.N.W. of Sullana.

Family MYTILIDÆ

Genus Mytilus, Linnæus.

Mytilus euglyphus, sp. n.

Plate I., Figs. 6, 7.

Description.—Shell subtriangular; antero-ventral margin concave; posterior margin convex, forming a large angle with the long straight postero-dorsal margin. Umbones nearly terminal. Valves with the greatest convexity along a curved line from the umbo to the postero-ventral extremity; in front of this line the shell slopes steeply to the margin; behind it the shell is convex and slopes gradually, except near the postero-dorsal margin where it is compressed. Ornamentation of numerous strong radial ribs; those on the anterior slope are curved, and more numerous and closer together (especially in front) than those on the posterior slope; along the line of greatest convexity of the valves some of the anterior ribs diverge at an acute angle from the posteriorly directed ribs. On the posterior slope the ribs are slightly curved, except near the postero-dorsal margin where they bend upwards. New ribs are intercalated, and others bifurcate towards the posterior and postero-dorsal margins. Hinge and interior not seen.

Remarks.—This appears to belong to the same group of species as *Mytilus Rigaulti*, Deshayes,[1] which is referred to the section *Arcomytilus* by Cossmann. It also shows some resemblance to a species from Lebu (Chili) named *Modiola Foncki* by Philippi.[2]

Two imperfect specimens (Plate I., Fig. 8) which were found in the Turritella Series may belong either to this species or to a closely allied form, but the ribs (except on the anterior slope) are relatively coarser.

Distribution.—Clavilithes Series, around Negritos, La Brea, etc.; possibly also Turritella Series.

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[1] *Description Anim. sans Vert.* ii. (1862), p. 29, vol. i. Pl. LXXIV. Figs. 23, 24.

[2] *Die Tert. u. Quart. Verstein. Chiles* (1887), p. 204, Pl. XLIII. Fig. 1.

Family OSTREIDÆ

Genus Ostrea, Linnæus.

Ostrea Inca, sp. n.

Plate I., Fig. 9. Plate II., Figs. 1, 2.

Description.—Shell rather small, more or less oval in outline, narrowing dorsally and ventrally, slightly inequilateral, sometimes sub-symmetrical.

Left valve with only a small surface for attachment; very convex between the anterior and posterior borders; sometimes nearly straight between the umbo and the opposite ventral margin, but more usually with the dorsal part slightly convex and the ventral part concave. Umbo straight or slightly curved.

Right valve very convex between the umbo and the ventral margin; moderately or slightly convex from front to back, but with the ventral part sometimes slightly concave.

Surface of both valves with distinct, regular, concentric lamellæ at intervals. Sometimes with indications of radial ribs between the lamellæ.

Remarks.—This species is similar in the form of the shell and in the regularity of the concentric lamellæ to some of the forms identified by de Gregorio as *Ostrea alabamiensis* var. *lingua-canis*, Lea,[1] from the Eocene of Alabama, but the concentric lamellæ are more numerous and the crenulations on the margins mentioned by Lea appear to be absent. A similar regularity in the concentric lamellæ is seen in *O. Weaveri*, Dickerson,[2] from the Martinez Group of California, but the form of the shell is different.

Distribution.—Turritella and Clavilithes Series, around Negritos.

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[1] I. Lea, *Contrib. to Geol.* (1833), p. 92, Pl. III. Fig. 72. A. de Gregorio, *Mon. Faune Eoc. Alabama* (1890), p. 174, Pl. XVIII. Figs. 9-13. Heilprin regards *O. lingua-canis* as a synonym of *O. alabamiensis*, Lea (*4th Ann. Rep. U.S. Geol. Surv.*, 1884, p. 309).

[2] *Univ. California Publ. Geol.* viii. (1914), p. 127, Pl. IX. Fig. 3.

Ostrea Buski, sp. n.

Plate II., Figs. 3, 4.

Description.—Shell sub-ovate in outline, slightly or moderately inequilateral. Left valve very convex, with the surface of attachment small; ornamented with strong angular radial ridges, some of which bifurcate, and between others new ridges are intercalated; concentric growth-lamellæ cross the ridges and interspaces, sometimes giving the summits of the ridges a notched or tuberculate appearance. Umbo bent or spirally curved. Anterior and posterior margins crenulate internally.

Distribution.—Turritella Series around Negritos. Possibly also Clavilithes Series.

Ostrea, sp.

Plate II., Fig. 5.

Another form, apparently distinct, is represented by a left valve of large size, with numerous radial ridges which sometimes bifurcate.

From the Turritella Series and Clavilithes Series, around Negritos.

Family PERNIDÆ

Genus Perna, Bruguière.

Perna arbolensis, sp. n.

Plate III., Fig. 1.

Description.—Shell nearly oblong, but rounded ventrally, moderately convex between the umbo and the postero-ventral border, sloping steeply in front, with the anterior marginal part slightly concave. Ventral margin convex, curving gradually up to the posterior margin which is nearly parallel to the anterior margin. Surface with numerous broad, rounded, concentric ribs.

Distribution.—Parinas Sandstone, $1\frac{1}{2}$ miles east of Negritos. Two larger specimens (about twice the size of the one described above) were found in the Lobitos Formation, 10 miles W.N.W. of Sullana, and probably belong to the same species.

Family CARDITIDÆ

Genus Venericardia, Lamarck.

Venericardia planicosta, Lamarck (group).

Plate III., Figs. 2, 3. Plate IV., Figs. 1-3.

Specimens of *Venericardia* of the *planicosta* type occur in the Turritella Series and the Clavilithes Series (including the Parinas Sandstone) in each of the areas where the Negritos Formation is exposed. They occur also in the lower part of the Lobitos Formation around Negritos and in the exposures of the Lobitos Formation W.N.W. of Sullana.

Form A.—There are two examples (Plate IV., Fig. 1) from the Turritella Series, of which the larger has a length of 70 mm.; these resemble closely in the form of the shell and in the flatness of the ribs specimens of similar size from the Bracklesham Beds of England and the Calcaire Grossier of France, but differ distinctly from the majority of those in having fewer and relatively broader ribs; the number of ribs in the European forms varies, however, and a few specimens with a relatively small number of ribs differ but little from the examples in the Turritella Series. The latter approach closely the North American form named *V. planicosta* var. *regia*, Conrad [1]

[1] *Foss. Shells Tert. Formations N. America* (Philadelphia, 1832), p. 20, Pl. v. Fig. 2; *Pacific Railroad Rep.* vol. v. (1857), p. 321, Pl. II. Fig. 6; *Amer. Journ. Conch.* vol. i. (1865), p. 8. A. de Gregorio, *Mon. Faune Eoc. Alabama* (1890), Pl. XXXII. Fig. 10. W. B. Clark, "Eoc. Deposits Mid. Atlantic Slope," *Bull. U.S. Geol. Surv.* No. 141 (1896), p. 80, Pl. XXI. Fig. 3, Pl. XXII. Fig. 2, Pls. XXIII.-XXV. W. B. Clark and G. C. Martin, *Maryland Geol. Surv. Eocene* (1901), p. 178, Pls. XXXVIII., XXXIX., XL., Figs. 1-3. G. D. Harris, "The Lignitic Stage," Pt. I., *Bull. Amer. Pal.* vol. ii. No. 9 (1897), p. 54, Pl. IX. Figs. 1, 2. A more elongate form, with broader grooves and narrower ribs, is figured by White, *Bull. U.S. Geol. Surv.* 18 (1885), Pl. I.

(1865) from the Aquia Formation of Maryland and the Wilcox Group of the south-eastern States. Near the umbo the ribs are narrower than the grooves, but they soon broaden, and at the ventral margin are much broader than the grooves.

Form B.—Specimens from the Clavilithes Series (Plate III., Fig. 2) resemble in form those from the Turritella Series and seem to be a later development of that type, from which they differ in the reduction of the grooves; these are deep and fairly broad in the neighbourhood of the umbo, but soon become narrow, and towards the ventral margin they are indistinct or obsolete. The narrowing of the grooves often gives the ribs a somewhat rounded appearance. The specimens from this horizon resemble the form of *V. planicosta*, figured by Harris[1] from the Upper Stage of the Wilcox Group and the Lower Claiborne Group; they may also be compared with *V. planicosta* var. *Horni*, Gabb,[2] from the Tejon Group,[3] California.

Form C.—Only one specimen from the Parinas Sandstone (Plate III., Fig. 3) has been examined. It is an old individual of large size with a very deep lunule. The umbones have a greater anterior curvature than in the specimens from the lower horizons, and the form of the shell is closely similar to that of large specimens from the Bracklesham Beds. The main point of interest, however, is seen in the further reduction of the grooves; except near the umbo

1 *Bull. Amer. Paleont.* vol. ii. No. 9 (1897), p. 54, Pl. x. Figs. 1-4.

2 *Geol. Surv. California, Palæont.* vol. i. (1864), Pl. xxiv. Fig. 157. C. A. Waring, *Proc. California Acad. Sci.* (4), vii. (1917), p. 95, Pl. xi. Figs. 3-5. See also G. D. Harris, *Bull. Amer. Palæont.* vol. vi. No. 31 (1919), p. 77, Pl. xxvii., xxviii. Figs. 1-3.

3 For distribution, see R. E. Dickerson, "Stratigraphy and Fauna of the Tejon Eocene of California," *Univ. Calif. Publ. Geol.* ix. (1916), p. 447.

they are narrow, and they become indistinct or obsolete at a much earlier stage than in the specimens from the underlying members of the Clavilithes Series, so that on the larger part of the shell the ribs are indicated by faint undulations only. A similarly great reduction in the development of the ribs and grooves is seen in *V. planicosta Merriami*, Dickerson,[1] from the Eocene (Siphonalia Zone) of Oregon.

The general change, therefore, which is shown by this succession of forms of *Venericardia* is a gradual reduction in the development of the ribs and grooves; in the earlier forms these are distinct throughout the life of the individual, and the ribs have flat surfaces, but later the grooves become narrower and tend to disappear near the ventral margin and the ribs become more rounded, and in the latest form the grooves are distinct only on the early part of the shell. The same general change has been noticed by Waring[2] in specimens from the Tejon and Ione Formations of California. He remarks: "The evolution of *Venericardia planicosta*, Lamarck, seems to have been from a square-ribbed variety to one with broad, rounded ribs, and then finally to a smooth form." In the form named *V. planicosta* var. *Smithi*, Aldrich,[3] from the Midway Group (Lower Eocene) of Alabama, the ribs remain narrower and the grooves deeper throughout life than in the specimens from the Turritella Series, and this would therefore appear to be a form characteristic of an earlier horizon than is represented in Peru.

Form D.—Three specimens from the Turritella

[1] *Proc. California Acad. Sci.* (4), iv. (1914), p. 118, Pl. xi. Fig. 1.

[2] *Journ. Geol.* vol. xxii. (1914), p. 785.

[3] G. D. Harris, "The Midway Stage," *Bull. Amer. Pal.* vol. i. No. 4 (1896), p. 59, Pl. iv. Fig. 14, Pl. v. Figs. 1, 2.

Series (Plate IV., Fig. 4) are distinguished from the form of *V. planicosta* above mentioned from that horizon by their much more inequilateral form; the anterior part of the shell is less produced and the posterior part more extended and somewhat angular; but although differing in form, the broad flat ribs and strong grooves are similar, but tend to disappear close to the ventral margin. This form resembles *V. clavidens*, Grzybowski;[1] but in the specimen figured by that author the ribs and grooves have a greater curvature and become obsolete at an earlier stage, and the posterior end of the shell is more angular.

Venericardia of the *planicosta* type is widely distributed in the Eocene deposits of the United States and has long been known. It has also been recorded from the Eocene of Trinidad[2] and of Tonosi, Los Santos Province, Panama.[3] By some authors the American forms have been identified definitely with Lamarck's *planicosta*; by others the various forms have been regarded as distinct species, sub-species or varieties; the principal names which have been given to these are *ascia*, Rogers; *densata*, Conrad; *Horni*, Gabb; *ionense*, Waring; *Merriami*, Dickerson; *marylandica*, Clark and Martin; *potapacoensis*, Clark and Martin; *regia*, Conrad; *Smithi*, Aldrich; *venturensis*, Waring. The relationship of these various

[1] *Neues Jahrb. für Min.* etc., Beil.-Band xii. (1899), p. 636, Pl. xix. Fig. 1. This form may also be compared with *V. potapacoensis*, Clark and Martin (*Maryland Geol. Surv. Eocene*, 1901, p. 179, Pl. xl. Fig. 4), from the Nanjemoy Formation (Upper Wilcox) of Maryland. See also *V. planicosta venturensis*, C. A. Waring, *Proc. California Acad. Sci.* (4), vii. (1917), p. 80, Pl. xi. Figs. 6, 7.

[2] C. J. Maury, *Journ. Acad. Nat. Sci. Philadelphia* (2), xv. (1912), p. 51, Pl. viii. Figs. 15, 16.

[3] T. W. Vaughan, *U.S. Nat. Mus. Bull.* 103 (1919), p. 548.

forms has not yet been fully worked out, so that for the present it does seem desirable to give new names to the forms found in Peru. The stages of development reached by these forms indicate that the deposits are represented by the Tejon Group of California and by the Wilcox and Lower Claiborne Groups of the eastern parts of the United States.

M. Cossmann[1] has compared specimens of the *planicosta* group from the United States with those of the Paris Basin, and believes that the former can be distinguished from the latter by the character of the hinge. He states that in American specimens the hinge is relatively higher; the teeth are less procumbent; the median tooth of the right valve is larger, more prominent, and less incised at the lower margin; the two pits of the right valve (and the corresponding teeth of the left valve) are less oblique and less sinuous; and the pit above the anterior adductor is smaller and less deep. For the American forms Cossmann adopts Conrad's name, *densata*.[2] From a comparison of English with North American specimens it seems to me that the differences noted are not so constant as stated by Cossmann in the case of the Paris Basin specimens.

Family LUCINIDÆ

Genus Lucina, Bruguière.

Lucina paytensis, sp. n.

Plate IV., Fig. 5.

Description.—Shell rounded, tending to become subquadrate, nearly equilateral, convex in the median part, but

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[1] *Bull. Soc. géol. France* (4), I. (1901), p. 652.

[2] *Journ. Acad. Nat. Sci. Philad.* (2), I. (1848), p. 130, Pl. xiv. Fig. 24.

compressed anteriorly and posteriorly. Antero-dorsal margin nearly straight, with a small ventral slope; postero-dorsal margin convex, curving ventrally; posterior margin truncated. Umbones of moderate size. A distinct ridge extends in a curve from the umbo to the postero-ventral extremity, and cuts off a concave postero-dorsal area. Lunule narrow, depressed. Surface ornamented with regular concentric linear ribs, which become rather more prominent on the postero-dorsal area; the interspaces between the ribs are flat and bear fine concentric ridges.

Remarks.—Compared with *L. diegoensis*, Dickerson,[1] from the Tejon Eocene of California, this species is less rounded in form, the valves less regularly convex, the lunule narrower, and the postero-dorsal area more distinct.

Distribution.—Lobitos Formation at Payta.

Family VENERIDÆ

Genus Callista, Mörch.

Callista (Macrocallista) Dickersoni, sp. n.

Plate IV., Fig. 6.

Description.—Shell with elongate-ovate outline, convex, the postero-dorsal part flattened; length rather more than one and a half times the height. Umbones at between a quarter and a third of the length from the anterior margin. Anterior margin rounded, ventral margin evenly convex; postero-dorsal margin long, slightly curved, sloping downwards. Posterior extremity sub-angular. Escutcheon narrow, elongate, depressed. Lunule not seen. Ornamentation consists of numerous narrow, usually sharp, concentric ribs; interspaces broader than the ribs, sometimes with concentric linear ridges. Hinge not seen.

Remarks.—This species is similar to a form from the Tejon Group originally named *Tapes Conradiana* by Gabb,[2] but referred to *Macrocallista* by Dickerson,[3] but the ribs are narrower and sharper, and the posterior extremity more angular.

Distribution.—Clavilithes Series, around Negritos, etc.

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[1] *Univ. California Publ. Geol.* ix. (1916), p. 484, Pl. XXXVII. Fig. 1.
[2] *Geol. Surv. California, Palæont.* i. (1864), p. 169, Pl. XXXII. Fig. 282.
[3] *Proc. California Acad. Sci.* (4), v. (1915), p. 42, Pl. III. Fig. 1.

Genus Meretrix, Lamarck (*sensu lato*).

Meretrix Bosworthi, sp. n.

Plate V., Fig. 1.

Description.—Shell sub-trigonal, not very inequilateral. Height nearly equal to the length. Antero-dorsal margin only slightly curved; anterior margin rounded, passing gradually into the regularly convex ventral margin; postero-dorsal margin long, slightly convex, sloping rapidly to the posterior extremity which is rounded. Umbones pointed, curved forward. Lunule elongate, depressed. Escutcheon not distinctly limited. Surface with concentric growth-ridges and lines. Hinge of right valve apparently with three cardinal teeth (the two anterior being stout), and a small laminar tooth between the anterior cardinal and the lunular margin; in front is a large pit (for the antero-lateral tooth of the left valve) and below it an antero-lateral tooth. Pallial sinus not clearly shown, but apparently of moderate size.

Remarks.—On account of insufficient knowledge of the hinge and pallial sinus this species is provisionally referred to *Meretrix* (*sensu lato*). The hinge shows some resemblance to that of *Sunetta* (*Meroëna*). The form of the shell is similar to that of a specimen, apparently from the Martinez Group, figured by Gabb[1] as probably a variety of *Venus varians*, but of which the hinge is not shown.

Distribution.—Clavilithes Series near Negritos; also occurs in the Turritella Series.

Meretrix negritosensis, sp. n.

Plate V., Fig. 2. Plate VI., Fig. 1.

Description.—Shell oval, inequilateral, moderately convex, height a little more than three-quarters of the length. Antero-dorsal margin concave; anterior margin rounded, passing gradually into the convex ventral margin; postero-dorsal margin long, sloping gradually to the rounded posterior extremity. Lunule depressed. Umbones curved forwards. Surface of shell with growth-lines. Hinge of right valve con-

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[1] *Geol. Surv. California, Palæont.* I. (1864), p. 161, Pl. XXIII. Fig. 141.

sisting of three cardinals, of which the anterior is stout, and in front of it near the lunular margin is a small laminar tooth; an antero-lateral tooth is present below the pit for the antero-lateral of the left valve.

Remarks.—The form of the shell is similar to some species of *Callista*, but there are differences in the character of the hinge and for the present it seems best to refer this species to *Meretrix* (*sensu lato*). The hinge resembles that of *M. Bosworthi* described above.

Distribution.—Clavilithes Series, around Negritos, etc. Rarely in the Turritella Series.

Family CARDIIDÆ

Genus Cardium, Linnæus.

Cardium, sp.

Plate V., Fig. 3.

A species of *Cardium* with strong radial ribs occurs in the Turritella Series, around Negritos, but owing to the hard closely adherent matrix the characters cannot be made out satisfactorily.

Family CORBULIDÆ

Genus Corbula, Bruguière.

Corbula peruviana, sp. n.

Plate V., Figs. 4, 5.

Description.—Shell sub-ovate or sub-oval, convex, the posterior part less convex than the anterior part, slightly inequivalve and inequilateral. Anterior margin rounded; ventral margin convex, its posterior part sloping upwards and forming a slight sinuosity near the postero-ventral angle; posterior margin short, oblique, forming an acute angle with the ventral and an obtuse angle with the postero-dorsal margin. Umbones nearly median, curving slightly forward, with a distinct carina extending to the postero-ventral angle and limiting a concave postero-dorsal area. Ornamentation of fine concentric ridges, and sometimes also very fine or faint radial ribs.

Affinities.—This species shows some resemblance to *C. Horni*, Gabb, as figured by Dickerson [1] from the Tejon Group, but is relatively higher and shorter, with the ventral margin more convex.

Distribution.—Turritella and Clavilithes Series, around Negritos, La Brea, etc.

Corbula Waringi, sp. n.

Plate V., Fig. 6.

Description.—Shell elongate, more or less sub-quadrate, moderately convex, slightly inequivalve and inequilateral. Anterior margin rounded; ventral margin only slightly curved, sloping gradually upwards to the postero-ventral angle. Posterior margin obliquely truncated; postero-dorsal margin nearly straight. Umbones nearly median, curved forwards, with a sharp carina passing in a curve to the postero-ventral angle and limiting a concave postero-dorsal area. Ornamentation consists of fine concentric ridges and fine radial ribs.

Remarks.—This species differs from *C. Horni*, figured by Dickerson (mentioned above), in its somewhat longer shell, less curved ventral margin, and higher posterior margin. It also shows some resemblance to *C. alabamiensis*, Lea,[2] from Claiborne.

Distribution.—Turritella and Clavilithes Series, around Negritos, La Brea, etc.

Corbula Arnoldi, sp. n.

Plate V., Figs. 7, 8.

Description.—Shell ovate, short, nearly equivalve and equilateral, convex, the convexity greatest between the umbones and the opposite ventral margin, and decreasing gradually towards the anterior and posterior ends. Anterior margin rounded; ventral margin regularly convex; posterior margin truncated, nearly vertical; postero-dorsal margin straight. Umbones nearly median, curving forwards, with a carina extending to the postero-ventral angle and limiting a concave postero-dorsal area. Ornamentation of numerous concentric ribs.

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[1] *Proc. California Acad. Sci.* (4), v. (1915), Pl. iv. Fig. 5.

[2] *Contrib. to Geol.* (1833), p. 45, Pl. I. Fig. 12.

Remarks.—The shell is relatively shorter and higher than in the last species, and the posterior margin is nearly vertical.

Distribution.—Turritella Series, around Negritos and La Brea.

Corbula parinasensis, sp. n.

Plate VI., Figs. 2, 3.

Description.—Shell sub-oval, elongate, nearly equilateral and equivalve, very convex, the convexity greatest in the median line and gradually decreasing towards the anterior and posterior ends. Antero-dorsal margin nearly straight, sloping ventrally; anterior margin rounded; ventral margin moderately convex, the posterior part sloping upwards to the postero-ventral angle; posterior margin truncated, slightly oblique; postero-dorsal margin nearly straight. Umbones almost median, with a small forward curvature, and an inconspicuous carina extending to the postero-ventral angle, and limiting a concave postero-dorsal area. Surface with growth-lines or concentric ridges.

Remarks.—This species shows some resemblance to *C. Arnoldi*, but the shell is much more elongated.

Distribution.—Parinas Sandstone, around Negritos.

Family PHOLADIDÆ

Genus Teredina, Lamarck.

Teredina, sp.

Plate VI., Figs. 4, 5.

A species of *Teredina* is represented by several internal casts, sometimes with parts of the shell preserved, from the Turritella Series, Clavilithes Series, and also the lower beds of the Lobitos Formation, around Negritos, etc.

CHAPTER III

DESCRIPTION OF THE GASTEROPODA FROM THE NEGRITOS AND LOBITOS FORMATIONS

Family SOLARIIDÆ

Genus Solarium, Lamarck.

Solarium Nelsoni, sp. n.

Plate VI., Figs. 6-8.

Description.—Shell depressed-conical. Spire slightly or moderately elevated. Whorls flattened or slightly convex; smooth or with faint spiral lines, crossed by growth-lines. At the outer margin of the whorls are two narrow bands separated by a groove. Margin of last whorl carinate. Base convex, except near the margin where there is a narrow band separated from the margin by a furrow. Base with fine spirals and growth-lines. Umbilicus about one-third of the diameter of the base, its margin without crenulations.

Remarks.—This species resembles *S.* (*Stellaxis*) *alveatum*, Conrad,[1] from the Midway Stage, Alabama, but the whorls are fewer and broader, and the umbilicus is not crenulated. The height of the spire varies, so that some specimens are more distinctly conical than others; this also appears to be the case in *S. alveatum*. In some specimens the whorls are smooth, but in others the spiral lines are distinct.

Distribution.—Turritella Series and Clavilithes Series, including the Parinas Sandstone, around Negritos, La Brea, etc.

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[1] *Foss. Shells Tert. N. America*, i. 3 (1833), p. 31, and ed. 2 (1835), p. 47, Pl. XVII. Fig. 3. A. de Gregorio, *Faune Eoc. Alabama* (1890), p. 133, Pl. XII. Figs. 13-19. M. Cossmann, *Paléoconch. comparée*, x. (1915), p. 168, Pl. VII. Figs. 10, 18.

Family NATICIDÆ

Genus Natica, Adanson.

Natica (*Naticina*), sp.

Plate VI., Fig. 9. Plate VII., Fig. 1.

Description. — Shell globose. Spire short, suture little impressed. Last whorl large, inflated, but with the sides compressed. Surface of shell smooth except for growth-lines. Aperture semi-ovate, pointed posteriorly. Inner lip thick, with callus largely concealing the umbilicus.

Remarks. — The shell resembles *Polinices subangulata*, Nelson,[1] from Zorritos.

Distribution.—Lower part of Lobitos Formation, two to three miles north-east of Negritos.

Genus Ampullina, Lamarck.

Ampullina Gabbi, sp. n.

Plate VII., Fig. 2.

Description. — Shell large, globose. Spire of moderate length, with convex whorls and impressed sutures. Last whorl rounded, greatest convexity behind the middle of the whorl. Surface of shell ornamented with faint spiral ribs. Aperture narrow and angular posteriorly; broad, rounded, and somewhat produced in front. Inner lip with flattened callus, almost covering the umbilicus. Umbilicus with a spiral carina.

Remarks.—This species shows some resemblance to *Ampullina vapincana* (d'Orbigny)[2] from the Lower Priabonian.

Distribution.—Negritos Formation, Cabo Blanco.

Ampullina paytensis, sp. n.

Plate VII., Figs. 3, 4.

Description.—Shell large, subglobose. Spire of moderate length; whorls convex; on the later whorls the part just in

[1] *Trans. Connecticut Acad. Arts and Sci.* ii. 1 (1870), p. 195, Pl. vi. Figs. 4, 12, 13.

[2] J. Boussac, *Études Paléont. sur le Nummulitique alpin* (1911), p. 327, Pl. xx. Figs. 11, 11*a*, 13.

front of the suture is flattened or concave. Last whorl convex, with distinct flattening near the suture. Surface nearly smooth. Aperture rounded and produced in front. Inner lip with thick callus, flattened anteriorly, partly covering the umbilicus.

Remarks.—This species belongs to the same type as *A. depressa*, Lamarck, from the Calcaire Grossier. The posterior flattening of the whorls gives it a resemblance to a form from the Tejon Group figured by Dickerson [1] as an example of *Amauropsis alveata*, Conrad, but from other figures showing the aperture this species appears to be distinct from that form.

Distribution.—Lobitos Formation, Payta.

Family TURRITELLIDÆ

Genus Turritella, Lamarck.

Turritella negritosensis, sp. n.

Plate VII., Figs. 5-7. Plate VIII., Figs. 1-3.

Description.—Shell conical; whorls with a prominent carina at about the anterior third, the parts above and below being flattened. A second carina, which is posterior to the first and sometimes becomes nearly as prominent, is gradually developed; in some specimens it appears on the early whorls and soon becomes conspicuous, or it may be present only on the last whorl or two. The space between the two carinæ is concave, and sometimes bears a small spiral rib. The shell is ornamented with fine spiral lines. The growth-lines bend back to the carinæ and pass between them transversely. On the base of the last whorl, which is rounded, are four spiral ribs.

Remarks.—The appearance of this species varies considerably according to the stage at which the second carina is developed, and every transition can be seen between individuals which are bicarinate almost throughout and those which

[1] *Proc. California Acad. Sci.* (4), v. (1915), Pl. v. Fig. 9. See also C. A. Waring, *ibid.* (4), vii. (1917), Pl. xv. Fig. 25. W. M. Gabb, *Geol. Surv. California, Palæont.* vol. i. (1864), p. 110, Pl. xix. Fig. 59, Pl. xxi. Fig. 111. R. Arnold, *Bull. U.S. Geol. Surv.* No. 396 (1909), Pl. iv. Fig. 21. Dickerson, *Univ. California Publications, Bull. Geol.* ix. (1916), Pl. xxxviii. Fig. 7.

are bicarinate on the later whorls only; in this respect it resembles *T. Mortoni*, Conrad,[1] from the Aquia Formation of Maryland and the Wilcox group of Alabama, but in that species the shell is more elongate, and the early whorls flattened and with several small spiral ribs.

In some specimens (Plate VIII., Fig. 3) the shell is more elongate than usual, but these do not differ in other respects from the common forms.

Distribution.—Turritella Series, around Negritos and La Brea.

Turritella Lissoni, sp. n.

Plate VIII., Figs. 4, 5.

Another species, found in the Turritella Series, differs from *T. negritosensis* in the further development of carinæ. In some the first four whorls are bicarinate, then a third carina is introduced posterior to the others, and on the penultimate whorl a fourth carina appears just above the suture. In other specimens the tricarinate character is developed at an earlier stage, and later other carinæ may be introduced, so that in some forms as many as six or seven carinæ are present on the whorls.

Distribution.—Turritella Series, around Negritos and La Brea.

Turritella Dickersoni, sp. n.

Plate VIII., Figs. 6, 7.

Description.—Shell greatly elongated. Early whorls with a spiral rib in front of the middle, and another immediately in front of the suture, with smaller spiral ribs above and below the first one. The spiral next the suture develops gradually on the later whorls and becomes a sharp, prominent, projecting collar. The spiral in front of the middle of the whorl becomes more prominent than the other small spirals;

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[1] *Journn. Acad. Nat. Sci. Philad.* vi. (1830), p. 221, Pl. x. Fig. 2. For other figures of *T. Mortoni*, see A. de Gregorio, *Faune Eoc. de l'Alabama* (1890), p. 122, Pl. xi. Fig. 7. W. B. Clark, "Eoc. Deposits Middle Atlantic Slope," *Bull. U.S. Geol. Surv.* 141 (1896), p. 69, Pl. xiii. W. B. Clark and G. C. Martin, *Maryland Geol. Surv. Eocene* (1901), p. 147, Pl. xxvi. M. Cossmann, *Essais de Paléoconch. comparée*, ix. (1912), p. 115, Pl. vii. Fig. 12. G. D. Harris, "Lignitic Stage," *Bull. Amer. Pal.* vol. iii. No. 11 (1899), p. 74, Pl. x. Figs. 3, 4.

above it the whorl is slightly concave, below it flattened. The growth-lines are concave between the collar-like rib and the next prominent rib below, and straight between this and the suture.

Remarks.—I do not know of any form with which this species can be closely compared. In *T. humerosa*, Conrad,[1] from the Midway and Wilcox Groups there is a tendency to develop a similar collar-like rib in front of the suture, and this is still more marked in *T. Merriami*, Dickerson,[2] from the Eocene of California, but these species differ in other respects from *T. Dickersoni.*

Distribution.—Turritella Series and Clavilithes Series, including Parinas Sandstone, around Negritos.

Turritella Bosworthi, sp. n.

Plate VIII., Figs. 8-10.

Description.—Shell elongate. Early whorls flattened or slightly concave, with two spiral ribs on the median part and one immediately behind the suture; in later stages of growth this last spiral gradually develops into a prominent collar-like rib and the whorls become concave. A fourth spiral appears later between the posterior of the three spirals already formed and the suture.

Distribution.—Clavilithes Series, including the Parinas Sandstone, around Negritos, La Brea, etc.

Turritella Douvillei, sp. n.

Plate VIII., Fig. 11.

Description.—Shell conical. Whorls angular, except those near the apex, the angular character becoming more marked on the later whorls. A sharp carina is present posterior to the middle of the whorls; the part of the whorl posterior to the carina is concave and usually smooth except for growth-lines, but sometimes a small spiral rib occurs near the carina. The part of the whorl in front of the carina is flattened and either nearly vertical or sloping inwards, but becomes slightly

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[1] See, for example, G. D. Harris, "The Lignitic Stage," Part II., *Bull. Amer. Pal.* vol. iii. No. 11 (1899), p. 75, Pl. x. Fig. 5.

[2] *Univ. California Publ. Geol.* vol. vii. (1913), p. 284, Pl. xiii. Fig. 6.

concave on the later whorls; it is smooth on the early whorls, but later small spiral ribs appear. Last whorl concave in front of the carina; base rounded. Aperture imperfectly preserved.

Distribution.—Turritella Series, around Negritos and La Brea.

Turritella anceps, sp. n.

Plate VIII., Figs. 12, 13. Plate IX., Figs. 1, 2.

Description.—Shell much elongated, tapering gradually to the apex. Early whorls of the spire at first rounded, afterwards subangular with a large flattened posterior part and a small flattened anterior part; ornamented with numerous small spirals. The later whorls rounded, relatively higher, with oblique sutures; sometimes with the posterior part concave; either smooth or with faint spirals. Aperture rounded in front; outer lip oblique.

Remarks.—The height of the later whorls and the obliquity of the sutures give a general form to the shell which is unlike that of *Turritella*, but the character of the early whorls indicates that it is very closely allied to species of that genus with subangular whorls; whether or not it should be referred to a new subgenus or genus can only be determined satisfactorily when other allied forms have been found. The species is represented by a large number of specimens.

Distribution. — Clavilithes Series, lower part (not in Parinas Sandstone), around Negritos, La Brea, Cabo Blanco, etc.

Turritella annectens, sp. n.

Plate IX., Figs. 3, 4.

This species is allied to *T. anceps*, and is a later development of that form. The spire is less elongate, and most of the whorls are subangular and similar to those of the first part of the spire in *T. anceps*. The last whorl is not rounded as in *T. anceps*, but owing to the more posterior position of the carina the flattened part behind it is narrow, and the main part of the whorl is flattened or slightly concave, and nearly vertical. The small spiral ribs are continued on to the last whorl.

Distribution.—Plentiful in the upper part of the Clavilithes

Series (Parinas Sandstone and Passage Beds below it), around Negritos, La Brea, etc. Also common in the lower part of the Lobitos Formation around Negritos.

Family MELANOPSIDÆ

Genus Morgania, Cossmann.

Morgania magna, sp. n.

Plate IX., Figs. 5, 6.

Description.—Shell elongate, broadest in front of the middle. Spire long, of about nine whorls, which are flattened; sutures linear. A few of the early whorls with fine spiral and stronger transverse ornament, other whorls smooth except for growth-lines. Part of the penultimate and last whorl often more convex than the preceding whorls. On the anterior part of the last whorl are four strong spiral ribs at the level of the posterior half of the aperture. Aperture with a short, broad, anterior canal. Outer lip with a large, broad, rounded sinus, in front of which the lip projects. Inner lip with callus.

Remarks.—Owing to weathering of the surface the character of the ornamentation on the early whorls is indistinct.

The examples of this species are of about twice the size of the type of the genus (*M. fusiformis*, Hislop) [1]; the spire is more elongated and the sinus in the outer lip is broader and less deep. The type came from beds of Eocene or perhaps late Cretaceous age, of Rájámandri, Nagpur; other examples have been described by Douvillé [2] from the Mæstrichtian of Louristan, Persia.

Smaller forms resembling this species, but with a more elongate spire on which the ornamentation persists for a longer period, are found in the Turritella Series.

Distribution.—Parinas Sandstone around Negritos. Negritos Formation at Cabo Blanco. Probably also in lowest beds of Lobitos Formation, 2 to 3 miles N.E. of Negritos.

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[1] S. Hislop, *Quart. Journ. Geol. Soc.* xvi. (1860), p. 177, Pl. VIII. Figs. 36*a-c*. Cossmann, *Paléoconch. comparée*, VIII. (1909), p. 164, Pl. III. Figs. 14, 15.

[2] J. de Morgan, "Mission scient. en Perse," III. Pt. IV, *Mollusques Foss.* (1904), p. 321, Pl. XLIV. Figs. 12-14.

Morgania costata, sp. n.

Plate IX., Figs. 7-10.

Description.—Shell elongate, broadest at the beginning of the last whorl. Spire acute, consisting of nine or ten whorls; early whorls with strong transverse ribs, slightly oblique to the axis, and three small spiral ribs, with tubercles at the points of intersection. On succeeding whorls the transverse ribs gradually disappear and the spirals become stronger and more numerous, eventually forming broad flattened ribs separated by furrows; these ribs are of unequal size, the second in front of the suture being usually the broadest. The spiral ribs are continued on to the last whorl, on the anterior part of which are somewhat smaller ribs. The ribs vary in number in different individuals. On the early whorls of the spire there is a narrow flattened posterior part or shelf which diminishes later and eventually disappears, when the whorls become evenly rounded; where the shelf is present the large part of the whorl in front is flattened. Aperture ovate, angular posteriorly. Anterior canal broad, deep, recurved. Outer lip with a large rounded sinus along the edge of which the lip is slightly reflected; in front of the sinus the lip projects outwards. Inner lip concave, thickened, slightly separated from the columellar edge.

Remarks.—The ornamentation of this species is of the same type as that in *Morgania persica* (Douvillé) [1] from the Mæstrichtian of Louristan in Persia.

Distribution.—Throughout the Turritella Series and Clavilithes Series, including Parinas Sandstone, around Negritos, La Brea, etc.

Genus Melanatria, Bowdisch.

Melanatria dimorphica, sp. n.

Plate IX., Fig. 11.

Description.—Shell elongate-conical. Whorls of the first half or more of the spire flattened, bearing several small spiral ribs; later a row of tubercles gradually appears posterior to the middle of the whorl, and afterwards the tubercles become

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1 "Mission scient. en Perse," par J. de Morgan, iii. Pt. IV. *Paléont. Mollusques foss.* (1904), p. 321, Pl. XLIV. Figs. 1-11.

prominent and pointed and the spiral ribs disappear. Anterior part of the last whorl angular, with a tendency to develop small tubercles at the angle. Base with four or more spiral ribs at the level of the inner lip. Aperture with a short anterior canal; inner lip concave; outer lip not preserved.

Remarks.—This species is represented by only a few specimens, with the aperture imperfect. It is similar to some forms of *M. auriculata* (Schlotheim)[1] from the Middle Eocene of Roncà and Mte. Pulli (Vicenza).

Distribution.—Turritella Series, around Negritos.

Melanatria acanthica, sp. n.

Plate IX., Figs. 12-14.

Description.—Shell elongate-conical. Spire of about nine whorls, sutures linear; first few whorls flattened or slightly convex, with the ornamentation not preserved but probably spiral; on about the fourth whorl a spiral row of tubercles appears near the posterior third of the whorl; the tubercles are well separated and become prominent or spinose on the later whorls. Above the row of tubercles a slight shoulder may develop. On the last whorl of the spire (or sometimes earlier), just behind the suture, another row of tubercles usually appears; this row is continued on the margin of the base of the body whorl, but is less prominent than the posterior row. The growth-lines bend back to the tubercles of the posterior row. On the base of the shell are several small spiral ribs. Aperture imperfectly preserved; inner lip regularly concave, with callus which becomes thick posteriorly; a slight posterior channel.

Remarks.—This species or variety appears to be a later form of *M. dimorphica* in which the tubercles appear at an earlier stage in development, and the individuals attain a larger size.

Distribution.—Clavilithes Series, including Parinas Sandstone, around Negritos, La Brea, etc.

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[1] A. Brongniart, *Mém. sur les terrains de sediment supér. calc.-trapp. du Vicentin* (1823), p. 69, Pl. III. Fig. 17. P. Oppenheim, *Zeitschr. d. Deutsch. Geol. Gesellsch.* xlvi. (1894), p. 376, Pl. xxvii. Figs. 6-8. A. de Gregorio, "Fauna eoc. di Roncà," *Ann. de géol. et de paléont.* livr. 21 (1896), p. 63, Pl. viii. Figs. 9, 10.

Melanatria propinqua, sp. n.

Plate X., Fig. 1.

This species differs from *M. dimorphica* in that the tubercles are at, or in front of, the middle of the whorls, and are in most cases elongated transversely; and the base of the last whorl is rounded instead of angular. When more specimens are available it may prove to be only a variety of *M. dimorphica*.

The specimen figured by Douvillé [1] and identified with *Cerithium vellicatum*, Bellardi,[2] appears to be an example of *M. propinqua;* it seems to me to be distinct from Bellardi's species.

Distribution.—Turritella Series, around Negritos.

Melanatria venusta, sp. n.

Plate X., Fig. 2.

Description.—Shell much elongated, conical. Whorls concave posteriorly, convex anteriorly, bearing axial folds, straight or curved, stronger on the anterior than on the posterior part of the whorls, with a tubercle near the middle which becomes stronger on the later whorls. Posterior part of the whorls with fine spiral ribs. Sutures linear.

Remarks.—The aperture is unknown and the species can only be provisionally referred to the genus *Melanatria*. It shows considerable resemblance to *M. Boriesi*, Doncieux,[3] from the Middle Lutetian of Corbières.

Distribution.—Clavilithes Series, around Negritos.

Genus PSEUDOGLAUCONIA, Douvillé.

Pseudoglauconia Lissoni, Douvillé.

1921. H. Douvillé, *Journ. Conchyl.* lxvi. p. 9, Fig. 1, Pl. II. Fig. 1.

Plate X., Fig. 3.

Description.—Shell large, elongate-conical. Early whorls of spire flattened, the ornamentation not preserved; later

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[1] *Journn. de Conchyl.* lxvi. (1921), Pl. II. Fig. 3.

[2] "Foss. nummulitiques de Nice," *Mém. Soc. géol. de France* (2), iv. (1852), p. 227, Pl. XV. Figs. 2, 3.

[3] "Foss. Nummulitiques de l'Aude et de l'Hérault, II. Corbières septentrionales," *Ann. Univ. de Lyon* (N.S.), fasc. 22 (1908), p. 206, Pl. XI. Figs. 15*a-c*.

whorls concave, with well-marked sutures; just behind the suture a few large pointed tubercles appear; the growth lines are concave forwards. Last whorl sometimes with a subsutural shelf with angular margin, in front of which the whorl is concave; the row of tubercles is a little in front of the middle of the whorl, beyond which the whorl contracts. At the margin of the base is a rounded carina. Growth-lines concave on the concave part of the whorl, bending forward at the level of the row of tubercles. Inner lip concave, with callus. Columella without folds.

Remarks.—A shorter and more conical form of this species occurs in the Clavilithes Series, and occasionally in the Turritella Series. Douvillé regards this species as the type of a new genus—*Pseudoglauconia*, but its relationship to *Glauconia* seems very doubtful.

Distribution.—Turritella Series and Clavilithes Series, including Parinas Sandstone; possibly also in lowest beds of Lobitos Formation; of the Negritos, La Brea, and Mogollon districts.

Genus Faunus, Montfort.

Faunus (?) *lagunitensis*, sp. n.

Plate X., Figs. 4-6.

Description.—Shell elongate-conical. Whorls of spire flattened, increasing very gradually in diameter; sutures linear on the early whorls, becoming a little more impressed on the later whorls; early whorls apparently smooth except for growth-lines which are concave forwards; subsequently, at a stage which varies in different individuals, oblique transverse folds are developed and extend from suture to suture, often in linear series over a number of whorls; the folds are slightly curved, sometimes almost straight. On the last whorl the folds become stronger and have a greater curvature; they do not extend on to the base of the shell, where small spiral ribs occur. Aperture imperfect.

Remarks.—Although closely related to *Faunus*, it is probable that this form is distinct from that genus. The earlier whorls of the spire are similar to those of *Faunus*, but on the later whorls there is no satisfactory evidence of a posterior sinus in the outer lip, and there is no carina such as is

developed in *F. rigidus* (Solander) and others. Transverse folds, somewhat similar to those in the present species, are seen in *F. undosus* (Brongniart).[1]

Distribution.—Lobitos Formation, 2½ miles E.S.E. of Punta Parinas, Lagunitas.

Family CERITHIIDÆ

Genus Cerithium (*sensu lato*).

Cerithium paytense, sp. n.

Plate X., Figs. 7-9.

Description.—Shell much elongated, conical, consisting of numerous whorls, with linear sutures; whorls flattened, except the last few, which become slightly convex. Whorls of the first part of the spire ornamented with four or five spiral ribs crossed by transverse folds which give rise to tubercles at the points of intersection; the transverse folds are sometimes varicose, and at first are nearly straight but later become concave and less prominent, ultimately disappearing; the spiral ribs, now flattened and smooth, continue for another whorl or two and then become obsolete, after which the remaining whorls are smooth except for growth-lines which are concave forwards.

Remarks.—Owing to the imperfect preservation of the aperture, no exact generic determination can be made at present, and the species is referred to *Cerithium* (*sensu lato*). On account of weathering and decortication the appearance of different specimens varies a good deal.

Distribution.—Lobitos Formation around Lagunitas and at Payta, perhaps also Sullana.

Cerithium negritosense, sp. n.

Plate XI., Fig. 1, 2.

Description.—Shell conical, rather elongate. Spire with flattened or slightly convex whorls, with strong transverse folds, which are rounded, slightly oblique, straight on the

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[1] *Terrains de sédiment supér. calc.-trapp. du Vicentin* (1823), Pl. III. Fig. 12.

early whorls but becoming slightly curved on the later whorls. Folds of successive whorls sometimes in a vertical line, sometimes alternating; sutures slightly impressed, more distinct on the later whorls, undulating where the folds alternate. Spiral ornament apparently absent, growth-lines present.

Last whorl larger than the preceding one; a spine sometimes develops on the folds near the aperture at the middle of the whorl; on the remainder of the last whorl folds are present on the posterior part only. Base rounded, with spiral ribs.

Aperture broad, rounded; inner lip concave, thickened. Anterior canal short. Posterior canal small, in mature specimens separated from the suture.

Remarks.—The early whorls of the spire are not preserved in any of the specimens, and the aperture is imperfect. In the general form of the shell and the character of the ornamentation this species is similar to *C. Chaperi*, Bayan,[1] from the Middle Eocene of Mte. Postale (Verona), but it is less elongate and apparently without fine spiral ribs; no close comparison of the aperture is possible at present, so the relationship of the forms cannot be definitely established. The separation of the posterior canal from the suture is found only in the mature stage. For the present this species is referred to *Cerithium* (*sensu lato*). *C. Chaperi* is placed by Oppenheim[2] in *Vertagus* and by Cossmann[3] in *Vulgocerithium.*

Distribution.—Clavilithes Series, upper part, around Negritos.

Cerithium Chatwini, sp. n.

Plate XI., Figs. 3-5.

Description.—Shell narrow, greatly elongated, consisting of a large number of flattened or slightly convex whorls, with linear sutures. Early whorls with one strong spiral between the middle of the whorl and the anterior suture, bearing numerous tubercles; and one small spiral behind the large

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[1] F. Bayan, *Mollusques tertiaires*, fasc. 1 (1870), p. 37, Pl. I. Figs. 4, 5. C. Mayer, *Journ. de Conchyliol*, XVIII. (1870), p. 333, Pl. XII. Fig. 2. A. de Gregorio, "Faunes tert. de la Vénétie," *Ann. Géol. et Pal.* livr. 14 (1894), p. 18, Pl. III. Figs. 72-76. There are four specimens of *C. Chaperi* from Mte. Postale in the Sedgwick Museum, Cambridge.

[2] P. Oppenheim, *Palæontographica*, xliii. (1896), p. 181, Pl. XII. Figs. 1, 2.

[3] *Paléoconch. comparée*, VII. (1906), p. 79.

spiral, and two in front of it. Later the tubercles on the main spiral become larger, fewer, and more widely separated, and eventually they form prominent blunt spines arranged in oblique axial rows often curving, usually five on a whorl. The smaller spirals become less distinct and may disappear on the later whorls. Growth-lines concave in front. Columella with two oblique folds.

Remarks.—The aperture is not preserved, so that this species can only be provisionally referred to *Cerithium* (*sensu lato*).

The striking character of the ornamentation recalls that of *Cryptaulax*.

Distribution.—Turritella Series, around Negritos and La Brea.

Genus Bezanconia, Bayle (in Fischer).

Bezanconia pupoidea, sp. n.

Plate XI., Figs. 6-8.

Description.—Shell pupoidal. Whorls of spire low, slightly convex or nearly flat, increasing slowly in diameter, smooth, with slightly concave growth-lines; sutures slightly impressed. Last whorl a little more convex, with the anterior part rounded; basal part with several spiral ribs; suture becoming channelled towards the aperture. Aperture with a short posterior canal separated from the margin of the whorl by a straight part of the posterior border, which is nearly at right angles to the outer lip. Inner lip somewhat thickened, separated from the columellar margin. Anterior canal apparently short.

Remarks.—Owing to the weathering of the specimens it is not possible to say whether the early whorls of the spire were ornamented or not. On account of the absence of the deep channelling of the sutures this species differs a good deal in appearance from the type of the genus, *B. spirata* (Lamarck), from the Lutetian of the Paris Basin, but a slight channelling is seen towards the aperture. The deep channelling is not, however, an essential character of the genus, as is shown by *B. Cossmanni*, Oppenheim,[1] from the Middle Eocene of Monte Postale, Verona. With the exception of the last whorl the

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[1] *Palæontographica*, xliii. (1896), p. 188, Pl. xv. Fig. 4.

shell of *B. pupoidea* shows more resemblance to *B. Cossmanni* than to *B. spirata*. The specimens of *B. pupoidea* are of about half the size of those of the two species mentioned. Another feature of difference in *B. pupoidea* is the apparent absence of folds on the columella.

The only other species of *Bezanconia* which appear to be known at present are *B. synarthrota*, Cossmann, from the Bartonian, and *B. pyrenaica*, Cossmann, from the Middle Eocene of Lérida.

Distribution.—Turritella Series, around Negritos and La Brea; possibly also Lobitos Series, 1 mile south of Talara.

Genus Potamides, Brongniart (*sensu lato*).

Potamides occidentalis, sp. n.

Plate XI., Fig. 9.

Description.—Shell elongate-conical, consisting of numerous flattened or slightly convex whorls, with slightly impressed sutures. Early whorls with three spiral ribs, of which the upper and lower are stronger than the middle rib; subsequently two more small ribs are introduced. The spiral ribs are crossed by folds somewhat oblique to the axis and often in linear series; at the points of intersection tubercles are developed. Last whorl with a rounded protuberance opposite the inner lip; base with several spiral ribs. Aperture broad, with a short, deep, anterior canal and a shallow posterior furrow; outer lip projecting posteriorly, angular in the middle, the posterior part being slightly concave and the anterior part convex and projecting.

Distribution.—Clavilithes Series, around Negritos, La Brea, etc.

Genus Tympanotonus, Schumacher.

Tympanotonus lagunitensis, sp. n.

Plate XI., Figs. 10-12.

Description.—Shell elongate-conical, whorls flattened, sutures rather deep. Each whorl with two spiral rows of large rounded tubercles, one just below, the other just above

the suture. The tubercles of the successive rows tend to be in more or less nearly vertical lines. On the later whorls a fine spiral rib is present in the space between the two rows of tubercles. On the last whorl, just in front of the anterior row of tubercles, are two small spiral ribs. Base of shell nearly smooth but with growth-lines curving sharply backwards. Aperture not preserved, but a sinuosity in the outer lip is shown by the growth-lines.

Remarks.—The character of the ornamentation on the early whorls cannot be seen. The shell is somewhat similar to *T. corbaricus*, Doncieux,[1] from the Ypresian, but is less elongate and with only two rows of tubercles.

Distribution.—Lobitos Formation, Lagunitas.

Genus TELESCOPIUM, Montfort.

Telescopium peruvianum, sp. n.

Plate XI., Figs. 13, 14.

Description.—Shell conical, consisting of numerous low, flattened whorls bearing many transverse folds. The folds are usually somewhat oblique, but sometimes axial, nearly straight but slightly curved near the anterior suture; on the later whorls the folds are sometimes more distinctly curved. Sutures linear. The periphery of the base is angular, with a deep furrow bounded by a small spiral rib above and by a stronger spiral below.

Remarks.—The aperture is imperfectly preserved. This species resembles a form from the Nari Beds (apparently Oligocene) of the Hála Chain, Sind, named *Cerithium subsemicostatum* by d'Archiac and Haime,[2] but the specimen figured is not sufficiently perfect to enable me to determine if the two species are really related. The species appears to be allied to *Telescopium*, and is provisionally referred to that genus.

Distribution.—Lobitos Formation, Lagunitas, and around Negritos; perhaps also Payta.

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[1] *Ann. Univ. de Lyon* (N.S.), fasc. 11 (1903), p. 335, Pl. v. Figs. 6*a-c*; and fasc. 22 (1908), p. 139, Pl. VIII. Figs 1*a-c*.

[2] *Descrip. des animaux foss. du groupe nummulitique de l'Inde* (1853), p. 300, Pl. XXIX. Fig. 5.

Family DIASTOMIDÆ

Genus Diastoma, Deshayes.

Diastoma americanum, sp. n.

Plate XII., Figs. 1, 2.

Description.—Spire elongate. Whorls slightly convex, sutures shallow. Transverse ribs numerous, strong, extending from suture to suture, and usually forming varices; slightly curved on the early whorls, but distinctly concave forwards on the later whorls. Spiral ribs and grooves are seen in the concave spaces between the transverse ribs, but are not preserved on the summits of the latter. Narrow spiral ribs are present on the base of the shell.

Remarks.—This species shows considerable resemblance to *D. costellatum* (Lamarck) *mut. alpinum*, Tournouer,[1] from the Lower Priabonian of the Alpine Eocene, but the transverse ribs are more numerous and more distinctly curved. Only a few specimens have been found, and in no case is the aperture preserved.

Distribution.—Clavilithes Series, around Negritos.

Family STROMBIDÆ

Genus Dientomochilus, Cossmann.

Sub-genus Ectinochilus, Cossmann.

Dientomochilus (*Ectinochilus*) sp., cf. *laqueata* (Conrad).

Plate XII., Fig. 3.

Six specimens of a species from the Lobitos Formation, 10 miles W.N.W. of Sullana, agree closely in form with *D.* (*E.*) *laqueata* (Conrad)[2] from the Claibornian of Alabama, but close comparison with that species is not possible at present

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[1] *Bull. Soc. géol. de France* (2), xxix. (1872), p. 493, Pl. v. Figs. 1*a-c*. J. Boussac, *Études pal. sur le nummulitique alpin* (1911), p. 273, Pl. xvii. Figs. 22-26.

[2] *Foss. Shells Tert. Formations N. America*, i. (4), 1833, p. 41, and No. 3 (1835), p. 38, Pl. xv. Fig. 4. *Rostellaria Cuvieri*, I. Lea, *Contrib. to Geol.* (1833), p. 160, Pl. v. Fig. 165. *Strombus canalis*, A de Gregorio, *Mon. faune éoc. de l'Alabama* (1890), p. 113, Pl. ix. Figs. 16-19.

since in all the specimens the surface of the shell is much weathered so that, except for the presence of spiral ribbing on the anterior part of the last whorl and faint indications of transverse ribs, the character of the ornamentation cannot be made out. The posterior canal is more extensively developed than in *D.* (*E.*) *laqueata*; it reaches to the apex of the spire and is sometimes continued down the other side as in *D.* (*E.*) *canalis*, Lamarck.

Family BUCCINIDÆ

Genus Pseudoliva, Swainson.

Pseudoliva parinasensis, sp. n.

Plate XII., Figs. 4-6.

Description.—Shell stout, pyriform. Spire very short, conical, with flattened whorls and inconspicuous sutures; ornamentation of fine spiral ribs. Last whorl large, ovoid, narrowing anteriorly, the posterior part with a smaller slope than the spire; the greatest width at about one-third of the distance from the suture to the anterior margin; surface smooth, except for spiral ribs between the narrow dorsal groove and the anterior end, and occasionally a few spirals near the suture. Dorsal groove ends above the middle of the columellar margin. A sharp carina bounds each side of the sulcus arising from the anterior sinus. Aperture imperfectly preserved, oval, the greatest width above the middle, with well-developed callus which sometimes extends on to the last whorl of the spire. Umbilicus not perforated.

Remarks.—This species resembles closely *P. vetusta* Conrad,[1] from the Eocene of Claiborne, etc., especially the form or variety named *fusiformis* by Lea,[2] but the last whorl is more ovoid owing to its greatest width being farther forward. The last whorl is less pyriform and less elongated than in *P. tejonensis*, Dickerson,[3] from the Tejon Group of California.

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[1] *Foss. Shells Tert. Form. N. America*, i. 3 (1833), p. 44, Pl. xv. Fig. 3. A. de Gregorio, *Faune éoc. de l'Alabama* (1890), p. 109, Pl. viii. Figs. 35-40. G. D. Harris, *Bull. American Paleont.* No. 1 (1895), p. 48.

[2] *Contrib. to Geol.* (1833), p. 162, Pl. v. Fig. 167.

[3] "Fauna of the Type Tejon," *Proc. California Acad. Sci.* (4), v. (1915), p. 63, Pl. vii. Fig. 2.

A few specimens of smaller size, with the callus only slightly developed, have been found in the earlier beds (Turritella and Clavilithes Series), and are somewhat more elongated and fusiform than those from the Parinas Sandstone. Specimens from the Lobitos Formation, 10 miles W.N.W. of Sullana, agree closely with those from the Parinas Sandstone, but others attain a much larger size and show an enormous development of callus with the last whorl encroaching on the spire.

Distribution.—Abundant in the Parinas Sandstone, around Negritos. A few smaller specimens are found below, in the Clavilithes and Turritella Series, and above in the Lobitos Formation (lower beds). It occurs plentifully also in the Lobitos Formation, 10 miles W.N.W. of Sullana.

Pseudoliva mutabilis, sp. n.

Plate XII., Figs. 7-11.

Description.—Shell large, thick. Spire short, consisting of about five whorls, with a distinct shoulder ridge; the part posterior to the shoulder is flattened or concave and slopes inwards, but becomes nearly horizontal on the later whorls; in front of the shoulder the whorls are convex and slope steeply. The whorls of the spire are ornamented with small spiral ribs and transverse growth-lines; the early whorls are without tubercles, but subsequently tubercles gradually develop on the shoulder angle and increase in size and are sometimes continued as a fold for a short distance in front of the shoulder.

Last whorl large, convex; the shoulder angle bears prominent tubercles or spines; the part between the shoulder angle and the suture is flattened and horizontal or sloping outwards. The surface of the last whorl is ornamented with numerous small spiral ribs and with growth-lines which bend backwards near the suture. The dorsal groove is conspicuous, and the shell is concave behind the carina which arises from the anterior sinus. Aperture large; inner lip with well-developed callus, which is thick posteriorly and sometimes partly fills up the suture of the last whorl.

Remarks.—The description given above is based on specimens from the Turritella Series (Figs. 7, 8); in specimens

from later beds modifications appear in some features. Thus in the Clavilithes Series (Fig. 9) the number of the shoulder tubercles on a whorl is greater than in the Turritella Series, and the callus, instead of just lining the suture of the last whorl, now covers the entire or almost the entire surface of the later whorls of the spire. In the Parinas Sandstone, except in small specimens, the shoulder tubercles on the last whorl become replaced by a sharp shoulder angle below which the whorl is flattened or slightly concave; the callus now covers over most of the whorls of the spire and is of considerable thickness, giving the whorls a rounded outline and altering entirely the appearance of the spire (Fig. 10). The shoulder angle and tubercles give this species some resemblance to some forms of *P. volutæformis*, Gabb,[1] from the Tejon Group of California, and to *P. Michelini* (Coquand),[2] from Algeria.

Distribution.—Turritella and Clavilithes Series, including the Parinas Sandstone; around Negritos.

Genus Nassa, Lamarck.

Nassa lagunitensis, sp. n.

Plate XII., Fig. 12. Plate XIII., Fig. 1.

Description.—Shell moderately elongate. Spire conical, pointed, with slightly convex whorls and moderately impressed sutures. Last whorl one and a half times the height of the spire, with the sides compressed and the anterior end contracted and rounded. Shell smooth, except for fine spiral lines, and spiral ribs on the anterior part of the last whorl; a narrow raised band is seen just in front of the sutures. Aperture ovate, narrow and angular posteriorly; outer lip slightly curved, rounded anteriorly, anterior channel broad; from it two carinæ start and meet the inner lip in front of the middle of the aperture; behind the posterior carina the shell is concave.

Distribution.—Lobitos Formation at Lagunitas, etc.; probably also 10 miles W.N.W. of Sullana.

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1 Dickerson, *Proc. California Acad. Sci.* (4), v. (1915), Pl. VII. Fig. 3*b*.

2 *Géol. et pal. région sud de Constantine* (1862), p. 268, Pl. XXX. Figs. 5, 6.

Family STREPTURIDÆ

Genus Strepsidura, Swainson.

Strepsidura pacifica, sp. n.

Plate XIII., Figs. 2-4.

Description.—Shell pyriform, inflated. Spire very short, the early whorls convex, the last one becoming flattened. After the protoconch the spire is at first ornamented with transverse ribs which become strong on later whorls; small spiral ribs develop subsequently to the transverse ribs. On the last whorl of the spire the transverse ribs become smaller, and soon either disappear or are represented by growth ridges only, but the spiral ribs continue. Last whorl of the shell with the posterior part more or less flattened and usually forming a rounded shoulder with the main part of the whorl; in senile forms this shoulder is more conspicuous and less rounded, and the last whorl encroaches on the spire. The posterior and anterior parts of the last whorl are ornamented with small spiral ribs, the middle part is usually smooth. Aperture rather narrow, with the outer lip slightly curved, a distinct posterior channel, and a recurved anterior canal from the edge of which arises a dorsal carina which extends to the columellar margin. Columella with one oblique fold in front. In old forms callus develops on the inner lip and becomes large and thick posteriorly, often extending on to the spire.

Remarks.—The development of the ornamentation is not clearly shown owing to the weathering of the early part of the spire, but so far as it can be made out from the smaller specimens in which senile characters are not present, it appears to follow closely the same course as in *Strepsidura turgida*, Solander.

In the Turritella Series only a few specimens have been found; nearly all are of small size and seldom show senile characters. In the Clavilithes Series this species is abundant, and in nearly all cases the callus is well developed and the last whorl encroaches on the spire. In the Parinas Sandstone this species is less numerous, but the specimens show senile characters (similar to those of the preceding Clavilithes Series).

Whitneya ficus, Gabb,[1] from the Tejon Group of California, is usually regarded as not more than sub-genus or section of *Strepsidura*, but is stated by Gabb to possess two or more folds on the columella; so far as one can judge from the figures, however, it appears to have one fold on the columella, and the dorsal carina arising from the anterior canal.

Distribution.—Turritella Series and Clavilithes Series (including Parinas Sandstone) and lower part of Lobitos Formation, around Negritos, La Brea, etc. Small forms from the Lobitos Formation at Lagunitas probably belong to this species.

Family FUSIDÆ

Genus Clavilithes, Swainson.

Clavilithes Harrisi, sp. n.

Plate XIII., Figs. 5, 6.

Description.—Shell fusiform, tapering gradually to the apex. Spire of about seven whorls, the early whorls with a few strong transverse ribs at first extending quite across the whorls, but on later whorls disappearing from the upper part and continuing for a time as rounded swellings on the lower part, but eventually disappearing altogether. Early whorls somewhat angular, last whorl of spire slightly concave above the middle, slightly convex below it. On the early whorls the spirals are uniform, later the lower spirals become more prominent than the upper ones, but subsequently become reduced or obsolete; the upper spirals remain small and sometimes continue on to the last whorl. A slight subsutural shelf is present on the later whorls. Last whorl nearly subcylindrical, with slightly convex sides, and slightly concave below the suture, rapidly contracting at the base; smooth or with spirals on the upper part and on the base. Aperture with a slight posterior channel. Outer lip nearly vertical. Protoconch and anterior canal not preserved.

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[1] *Geol. Surv. California Palæontology*, vol. i. (1864), p. 104, Pl. xxviii. Fig. 216. Dickerson, *Proc. California Acad. Sci.* (4), v. (1915), p. 69, Pl. ix. Figs. 5*a-d*. This species is placed in the genus *Strepsidura* by G. D. Harris, *Proc. Acad. Nat. Sci. Philadelphia* (1895), p. 71, Pl. vii. Fig. 1 (from the Lower Claiborne of Texas).

Remarks.—This species resembles *C. Kennedyanus*, Harris,[1] from the Lignitic and Lower Claiborne Stages of Alabama and Texas, but the spire is less elongate, the whorls are relatively higher, and the spiral ornamentation persists for a longer period.

Distribution.—Clavilithes Series, around Negritos. Poorly preserved specimens from the Lobitos Formation, 2 miles east of Punta Parinas, probably belong to this species.

Clavilithes peruvianus, sp. n.

Plate XIII., Figs. 7-9.

Description.—Shell slender, fusiform. Spire acute, formed of about seven whorls; early whorls with a few broad transverse ribs or swellings and numerous fine spirals; the former soon disappear and the whorls then become more rounded, but their convexity is small; the spirals continue after the transverse ribs have disappeared, but gradually diminish in size and ultimately disappear except in some cases just in front of the suture. The last whorl embraces the preceding as far as the contracted base; surface smooth except for growth-lines, which are slightly concave in front; an indication of a very narrow subsutural depression is sometimes seen; in front of the suture on this and some earlier whorls is a very shallow sulcus. Aperture imperfectly preserved. Anterior canal slightly curved.

Remarks.—In the general form of the shell, and the slightly convex and nearly smooth later whorls, this species is similar to *C. raphanoides* (Conrad)[2] from the Eocene (Claibornian) of Alabama, but a large part of the spire is missing from the specimen figured by Conrad, so that the character and development of its ornamentation is not known; it differs from *C. raphanoides* in the relatively higher whorls, in the more oblique sutures, and in the less rounded form of the lower part of the last whorl. The protoconch is not preserved in any of the specimens, and owing to weathering the details of the

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[1] *Proc. Acad. Nat. Sci. Philadelphia* (1895), p. 78, Pl. vii. Fig. 8, and *Bull. American Pal.* iii. No. 11 (1899), p. 44, Pl. v. Fig. 8. A. W. Grabau, "Phylogeny of Fusus," etc., *Smithson. Misc. Coll.* xliv. No. 1417 (1904), p. 131.

[2] *Foss. Shells Tert. Formations N. America*, i. 3 (1835), p. 54, Pl. xviii. Fig. 8. A. W. Grabau, "Phylogeny of Fusus," etc., *Smithson. Misc. Coll.* xliv. No. 1471 (1904), p. 130.

development of the ornamentation on the whorls cannot be made out clearly.

Distribution.—Abundant in the Clavilithes Series including the Parinas Sandstone; present occasionally in the lower beds of the Lobitos Formation, and perhaps in the upper beds of the Turritella Series; around Negritos, La Brea, etc.

Clavilithes pacificus, sp. n.

Plate XIII., Fig. 10. Plate XIV., Figs. 1, 2.

Description.—Early part of spire slender, acute, with relatively high whorls which increase in width slowly and gradually; later whorls broader, increasing in width more rapidly. First few (three or four) whorls of spire slightly convex, ornamented with a few transverse ribs and numerous nearly uniform spirals; the transverse ribs soon disappear (fourth or fifth whorl), and at about the same time a subsutural shelf, which is nearly horizontal, gradually develops and grows outward at the top, forming a small collar; the part of the whorl below the collar is nearly vertical and bears spiral ribs. The shelf continues to be prominent on the later whorls, but the collar soon disappears and the shelf angle becomes rounded; the shelf now slopes inwards. The spiral ribs on the later whorls become faint or indistinct. Sutures depressed. Last whorl large, overlapping a considerable part of the preceding whorl; its main part subcylindrical, with flattened or slightly concave sides; rapidly contracted at the base. Surface nearly smooth, except for small spirals below the shelf angle. Aperture ovate, narrow, and channelled posteriorly. Outer lip slightly convex. Anterior canal long, nearly straight.

Remarks.—In the early appearance and subsequent marked development of the subsutural shelf this species resembles *C. tabulata*, Dickerson,[1] from the Eocene of Marysville Buttes, California, but the overlap of the whorls is relatively greater and the last whorl is more cylindrical in form; comparison of the early stages in the development is not possible until more perfect specimens of *C. tabulata* have been found. Of European forms this species corresponds in its

[1] *Univ. California Publ. Bull. Dep. Geol.* vii. (1913), p. 283, Pl. xii. Fig. 7.

development to some forms of *C. subscalaris*, Grabau,[1] from the Middle Eocene, but the convex whorls are replaced at an earlier stage by those with a subsutural shelf and vertical lower part, and this form of whorl continues for a longer period; also there is a more considerable overlap of the whorls.

Distribution.—Clavilithes Series, becoming abundant in the Parinas Sandstone; fairly common also in the lower part of the Lobitos Formation; around the Negritos district.

Clavilithes incertus, sp. n.

Plate XIV., Fig. 3.

Description.—Spire acute, with strong transverse ribs or swellings and small spirals; the transverse ribs continue as far as the later part of the last whorl of the spire; a subsutural shelf appears before these ribs disappear and soon becomes strong; after the loss of the ribs a concave depression develops below and parallel to the shelf angle. Last whorl overlapping about half of the convex part of the preceding whorl; the shelf now slopes inward, and the concave belt below it becomes deeper; the remainder of the whorl is convex and tapers gradually in front. The surface is smooth except for faint spirals seen chiefly on the anterior part.

Remarks.—This species is similar to the form of *Rhopalithes Noæ* (Chemnitz),[2] in which the transverse ribs continue on to the last whorl of the spire. Whether it belongs to the *Rhopalithes* series (apparently unknown in America) or to *Clavilithes* cannot be determined until the protoconch is found, but an indication of a plication on the columella suggests a connection with the former.

Owing to the imperfect preservation of the surface the details of the spiral ornamentation cannot be made out. Only two specimens have been found, in both of which the aperture is broken.

Distribution.—Clavilithes Series including Parinas Sandstone, around Negritos. Specimens probably belonging to

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[1] "Phylogeny of Fusus," etc., *Smithson. Misc. Coll.* xliv. No. 1417 (1904), p. 114, Pl. x. Fig. 1, Pl. xii. Figs. 1-3, 7, 8, 10-12.

[2] A. W. Grabau, "Phylogeny of Fusus," etc., *Smithson. Misc. Coll.* xliv. No. 1417 (1904), p. 139, Pl. xvi. Fig. 3.

this species, but with the margin of the subsutural shelf more angular, occur in the lower part of the Lobitos Formation east of Negritos.

Genus Sycum, Bayle.

Sycum americanum, sp. n.

Plate XIV., Fig. 4.

Description.—Shell subpyriform. Spire short, the apical part acute formed of three narrow, convex whorls; the three succeeding whorls broader, with flattened, gently sloping surface. Last whorl large; the posterior part flattened, sometimes slightly concave, sloping uniformly with the last whorls of the spire and forming a rounded shoulder with the main part of the whorl, which is flattened or slightly convex; the anterior part of the whorl is contracted. Surface smooth or with faint spiral lines. Aperture elongate, narrow, and channelled posteriorly; main part of the outer lip slightly convex; inner lip with callus which becomes thick posteriorly.

Remarks.—Of the known species of *Sycum* this resembles some forms of *S. bulbus* (Solander) from the Middle Eocene of the Hampshire and Paris Basins, such as the variety *subcarinata*, Lamarck, but the last whorl (as seen from above) increases in width more slowly and consequently the aperture is narrower, and the broad part of the whorl is relatively longer so that the whorl is less rounded in form. A species identified as *Sycum bulliforme* (Lam.) has been recorded by Oppenheim [1] from the Eocene of the Cameroons.

Distribution.—Parinas Sandstone, around Negritos.

Family VOLUTIDÆ

Genus Volutospina, R. B. Newton.[2]

Volutospina peruviana, sp. n.

Plate XIV., Figs. 5-7. Plate XV., Figs. 1-5.

Description.—Spire very short, its early whorls with strong transverse ribs and small spirals; a shoulder ridge is soon

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[1] E. Esch, F. Solger, P. Oppenheim, and O. Jaekel, *Beitr. z. Geol. v. Kamerun* (1904), p. 278, Pl. IX. Fig. 32.

[2] *Proc. Malacol. Soc.* vii. (1906), p. 103. *Volutilithes*, Swainson, 1840, *non* 1831.

developed, on which tubercles appear, and above these the ribs cease. On the later whorls of the spire the transverse and spiral ribs gradually become smaller and ultimately disappear or the spirals alone remain. The last whorl forms the main part of the shell; its small posterior part is flattened and either nearly horizontal or with a small or moderate slope, and it forms a shoulder angle with the main part of the whorl. The shoulder angle bears about eleven strong tubercles or spines which, in old individuals, sometimes develop into a shoulder keel on the later part of the whorl. The main part of the last whorl is flattened, without folds, and smooth except for growth-lines; this whorl becomes narrower and concave anteriorly. Aperture elongate, rather narrow, with a posterior channel; outer lip slightly curved; anterior canal rather short, with a deep sinus from each side of which a dorsal carina is developed; the posterior carina is the stronger, and just behind it the whorl is concave and bears spiral striæ. Columella with three strong, nearly equal, moderately oblique folds. Inner lip with callus which often extends on to the spire, sometimes merely wrapping round the margin of the shoulder tubercles, in other cases covering the whole of the spire, and sometimes extending over part or even the whole of the last whorl; it is often thick, so that the shoulder spines cannot be seen on the surface.

Remarks.—The great development of the callus in this species is comparable with that in *V. depressa*, Lamarck, from the Eocene, and *V.* (*Athleta*) *rarispina*, Lamarck, from the Miocene, and still more with that in *V. petrosus*, Conrad,[1] from the Eocene of the United States (Wilcox and Claiborne Groups and Jackson Formation), but even in this last species it does not reach such an extreme development as in *V. peruviana*. On the whole the extent of the callus increases in passing from earlier to later horizons. Thus in the Turritella

[1] T. A. Conrad, *Foss. Shells of the Tertiary N. America*, No. 3, ed. 2 (1835), p. 41, Pl. XVI. Fig. 2. A. de Gregorio, *Faune éoc. de l'Alabama* (1890), p. 63, Pl. IV. Figs. 50-62. W. B. Clark and G. C. Martin, *Maryland Geol. Surv. Eocene* (1901), p. 130, Pl. XXI. Figs. 4, 5. Also *V. Tuomeyi*, T. A. Conrad, *Journ. Acad. Nat. Sci. Philadelphia* (2), iv. (1860), p. 298, Pl. XLVII. Fig. 35. A. de Gregorio, *Faune éoc. de l'Alabama* (1890), p. 70, Pl. V. Fig. 22, W. B. Clark, *Bull. U.S. Geol. Surv.* No. 141 (1896), p. 65, Pl. X. Fig. 1. M. Cossmann, *Paléoconch. comparée*, 3 (1899), p. 141, Pl. V. Fig. 5. G. D. Harris, "The Lignitic Stage," *Bull. Amer. Pal.* III. No. 11 (1899), p. 33, Pl. IV. Fig. 1.

Series (Plate XIV., Figs. 5-6) it is only in a few specimens that it covers the spire; usually it either wraps round the lower part of the shoulder spines of the spire or is limited to the region of the inner lip. In the Clavilithes Series (Plate XV., Figs. 1, 2) it usually covers the spire and part of the last whorl. In the Parinas Sandstone (Plate XV., Figs. 3-5), except in small specimens, the whole of the last whorl, as well as the spire, is usually covered by callus which is often so thick that the shoulder spines are hidden from view [1]; one example of this type has also been found in the Lobitos Formation N.E. of Negritos. It may also be noted that the specimens from the Parinas Sandstone are somewhat dwarfed compared with those from earlier horizons.

It should be stated, however, that there are a few forms which show distinctly senile characters, but which do not show an extensive development of callus.

In several features *V. peruviana* resembles *V. athleta*, Solander, from the Barton Beds of England and from the Upper Eocene of the Paris Basin, but the anterior canal is less produced, the columellar folds are stronger, and the dorsal carinæ are more prominent. Owing to the imperfect preservation of the ornamentation on the early whorls, the details of the development cannot be made out satisfactorily. The development and phylogeny of the races of *V. petrosus* have been studied by Burnett Smith,[2] who regards *V. limopsis*, Conrad, as the ancestral form of the series. Conrad's species is the type of the genus *Volutocorbis*, Dall. It may also be noted that *V. petrosus* is placed by some authors [3] in the genus *Volutilithes* (Swainson, 1840, *non* 1831), whilst the senile form of the same species (named *V. Tuomeyi*, Conrad) is referred [4] to the genus *Athleta*. Until more is known of the development and phylogeny of *V. peruviana* it seems best to refer this species to *Volutospina* (= *Volutilithes*, Swainson, 1840, *non* 1831), but further study may show that it should be regarded as the type of a new genus.

[1] Compare these forms with *Psilocochlis McCalliei*, Dall, *Smithson. Misc. Coll.* l. (1908), p. 22, Figs. 11-13.

[2] *Proc. Acad. Nat. Sci. Philadelphia*, lviii. (1906), p. 52, and (1907), p. 229. See also Smith, "Senility among Gastropods," *ibid.* lvii. (1905), p. 345, Pl. xxx. Figs. 1-5.

[3] M. Cossmann, *Paléoconch. comparée*, iii. (1899), p. 137.

[4] Cossmann, *ibid.* p. 141.

Distribution.—Turritella Series and Clavilithes Series, including Parinas Sandstone, around Negritos, La Brea, etc. Negritos Formation, Cabo Blanco. Lobitos Formation 10 miles W.N.W. of Sullana; occasionally present in the lower part of the Lobitos Formation around Negritos.[1]

Volutospina crassiuscula, sp. n.

Plate XV., Figs. 6, 7. Plate XVI., Fig. 1.

Description.—Shell large, thick, pyriform, with a short conical spire. Whorls of the spire with strong transverse ribs, which tend to develop a node just above the suture; on the last whorl of the spire the ribs become reduced and eventually disappear. A shoulder ridge is recognisable on the early whorls, but the later whorls of the spire become flattened. Sutures inconspicuous, only slightly impressed. Last whorl large, inflated, becoming narrower in front, smooth except for growth-lines which bend back at the suture. Aperture elongate, outer lip convex, becoming more nearly straight in old specimens. Posterior channel becomes more marked in old individuals and develops into a deep sinus in senile forms. Inner lip with well-developed callus. A strong dorsal carina arises from the anterior sinus, and behind it the shell is concave. Columella with three strong, only slightly oblique folds.

Remarks.—This species is represented by only a few specimens, none being perfect. The character of the ornamentation on the spire cannot be made out fully, but is sufficient to indicate a coarsely ribbed ancestor. The deep posterior sinus in senile forms is comparable with that in old forms of *V. selseiensis*, Edwards. The smaller forms of *V. crassiuscula* show some resemblance to *V. pulcinellæformis* (de Gregorio)[2] from the Middle Eocene of Mte. Postale, Verona.

Distribution.—Turritella Series, around Negritos.

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[1] Since the above was in type Douvillé (*Journ. Conchyl.* lxvi. (1921), p. 1, Pl. I. Fig. 4) has figured an imperfect specimen of this species from the "Eocene of Peru," and refers it to his genus *Eovasum*, the type of which is *Turbinella frequens*, Mayer-Eymar (*Journ. Conchyl.* xliii. (1895), p. 47, Pl. II. Fig. 7). Whilst there are some points of similarity, the more important characters of the Peru species seem to me to connect it with the Volutids.

[2] *Ann. géol. et paléont.* livr. 14 (1894), p. 24, Pl. IV. Fig. 128. P. Oppenheim, *Palæontographica*, xliii. (1896), p. 202, Pl. XIII. Figs. 5, 5*a*.

Volutospina meridionalis, sp. n.

Plate XVI., Fig. 2.

Description.—Shell small, fusiform. Spire moderately high, with strong narrow transverse ribs. Last whorl with a narrow shoulder ridge, in front of which the whorl is ornamented with strong transverse ribs or folds which usually disappear on the narrow anterior part of the whorl; the entire surface of the whorl is ornamented with numerous spiral ribs.

Distribution.—Clavilithes Series (only two specimens), and lower part of Lobitos Formation; around Negritos.

Family OLIVIDÆ

Genus Olivancillaria, D'Orbigny.

Olivancillaria eocenica, sp. n.

Plate XVI., Figs. 3, 4.

Description.—Shell rather short and broad. Spire short, more or less acuminate, consisting of about five whorls, the last broader than the earlier ones, the sutures canaliculate. Last whorl large, the greatest breadth at a short distance in front of the suture, the main part of the whorl flattened and narrowing gradually to the anterior end; surface smooth except for growth-lines, occasionally with a few small transverse ribs. Dorsal area bounded by a groove which ends at about the middle of the inner lip. Aperture elongate, very narrow posteriorly and canaliculate, rather broad in front with a broad anterior notch. Outer lip only slightly curved, sharp, nearly vertical. Columellar edge with one or two folds in front. Inner lip with a thick callus, broad behind, covering the whorls of the spire but not concealing the sutures.

Remarks.—This species agrees more nearly with *Olivancillaria* [1] than with other allied genera, but the sutures of the spire are not concealed by callus as in the typical forms of *Olivancillaria.*

Distribution.—Turritellæ Series and Clavilithes Series, including Parinas Sandstone, around Negritos, La Brea, etc.

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[1] Cossmann, *Paléoconch. comparée*, iii. (1899), pp. 49-51.

Sub-genus Agaronia, Gray.

Olivancillaria (*Agaronia*) *peruviana*, sp. n.

Plate XVI., Figs. 5, 6.

Description.—Shell small, elongate-ovate. Spire rather short, pointed, with flattened or slightly convex whorls. Sutures narrowly channelled. Last whorl large, moderately convex, greatest diameter near the posterior third; smooth except for growth-lines. Aperture narrow posteriorly, broader anteriorly, truncated in front by a broad and deep notch, behind which a narrow groove passes to the columellar margin near the posterior third of the aperture. Columellar edge with callus, and five or six narrow, oblique ridges, three long, the others shorter. Outer lip slightly curved, nearly vertical, somewhat projecting anteriorly.

Remarks.—The shell in this species is relatively shorter and smaller than in *O.* (*Agaronia*) *alabamiensis* (Conrad) from the Eocene of Claiborne.

Distribution.—Lobitos Formation of Lagunitas; perhaps also Sullana.

Family TURRITIDÆ

Genus Surcula, H. and A. Adams.

Surcula occidentalis, sp. n.

Plate XVI., Figs. 7-10.

Description.—Shell broad, fusiform. Spire conical, consisting of about seven whorls; a row of tubercles is present, and on the early whorls is just above the suture, but gradually becomes farther from it on the later whorls; the part of the whorl posterior to the tubercles is moderately or slightly concave, the part in front of the tubercles is nearly vertical and forms an obtuse angle with the part behind. Last whorl large, with a row of prominent tubercles on the angle of the whorl; the whorl is concave behind the row tubercles, convex in front of it, but becomes concave on the anterior part. The surface is usually smooth except for growth-lines which bend back and form a sinus either at the angle of the whorl or immediately above it. Sometimes faint spiral ribs are

present on the anterior part of the whorl. Aperture ovate, outer lip not preserved, inner lip with callus. Columellar margin concave. Canal of moderate length, somewhat bent.

Remarks.—This species shows a general resemblance to the form named *Pleurotoma acutinoda* by Philippi,[1] but in the only specimen figured the aperture is imperfect and a close comparison is not possible at present. *S. occidentalis* resembles in form *S. ingens* (Mayer-Eymar),[2] from the Eocene of Egypt, but obviously differs in other features. Several species of *Surcula* have been described from the Eocene of California.[3] *S. occidentalis* differs from the type of the genus in having the sinus either at or immediately above the angle of the whorl, but in this respect it is similar to some other species referred to *Surcula*.

Distribution.—Abundant in the lower part of the Clavilithes Series, but less plentiful in the Parinas Sandstone; a few specimens in the Turritella Series; around Negritos, La Brea, etc.

Surcula Thompsoni, sp. n.

Plate XVII., Figs. 1, 2.

Description.—Shell fusiform. Spire rather high; whorls with a row of prominent tubercles, at first a little behind the suture, becoming gradually farther from it on later whorls, and being nearly median on the last whorl of the spire; the part of the whorl posterior to the tubercles is concave, and forms an angle with the part in front which is nearly vertical; the surface of the whorl is marked with growth-lines, and on some specimens faint spiral ribs are seen.

Last whorl concave between the angle and the suture, convex in front of the angle, but becoming concave towards the anterior end; ornamented with fine spiral ribs on the posterior concave part, and with stronger spirals on the remainder of the whorl; the growth-lines form a rounded sinus above the

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1 *Die Tert. und Quart. Verstein. Chiles* (1887), p. 37, Pl. I. Fig. 8.

2 *Journ. de Conchyl.* XLIII. (1895), p. 50, Pl. IV. P. Oppenheim, *Palæontographica*, XXX. (3), (1906), p. 332, Pl. XXIV. Fig. 26.

3 See W. M. Gabb, *Geol. Surv. California Palæont.* II. (1869), p. 150. R. E. Dickerson, *Univ. California Publ. Geol.* VII. (1913), pp. 278, 279; VIII. (1914), pp. 148, 149; IX. (1916), pp. 498, 499. *Proc. California Acad. Sci.* (4), V. (1915), pp. 70-72.

angle of the whorl. Outer lip not preserved; inner lip with slight callus. Canal moderately long.

Remarks.—In this species the shell is more elongate than in *S. occidentalis*, also the tubercles are fewer and more prominent, the sinus is above the angle of the whorl, and the spirals on the last whorl are much more prominent.

A specimen from the Turritella Series (Plate XVII., Fig. 8) differs from the form described above in having a more elongate spire, and in the posterior part of the whorls being more deeply concave.

Distribution.—Clavilithes Series, around Negritos, La Brea, etc.

Family CONIDÆ

Genus Conus, Linnæus.

Conus (*Lithoconus*), sp.

Two specimens not sufficiently well preserved for specific description were found in the Lobitos Formation 10 miles W.N.W. of Sullana. *C. sauridens*, Conrad,[1] from the Claibornian of Alabama is somewhat similar but has a more elongate shell.

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[1] *Foss. Shells Tert. Form. N. America*, i. (3) (1833), p. 33; ed. 2 (1835), p. 38, Pl. xv. Fig. 7.

CHAPTER IV

DESCRIPTION OF THE GASTEROPODA FROM THE ZORRITOS FORMATION

Genus Solarium, Lamarck.

Solarium sexlineare, Nelson.

Plate XVIII., Fig. 1.

1870. E. T. Nelson, *Trans. Connecticut Acad.* ii. Pt. I. p. 194, Pl. vi. Fig. 11.
1899. J. Grzybowski, *Neues Jahrb. für Min.* etc., Beil.-Bd. xii. p. 642, Pl. xx. Fig. 13.

The type of this species came from Zorritos. Nelson figured a view of the base only, and Grzybowski gave a side view. Two specimens were obtained from the Zorritos Formation of Quebrada Charan.

Genus Turritella, Lamarck.

Turritella infracarinata, Grzybowski.

Plate XVIII., Figs. 2, 3.

1899. J. Grzybowski, *Neues Jahrb. für Min.* etc., Beil.-Bd. xii. p. 643, Pl. xx. Fig. 5.

Remarks.—The earlier whorls are more rounded than the later ones, and the main ribs are of nearly equal size. The angular character of the succeeding whorls is due to the increase in size of one of the ribs at about a third of the distance from the anterior to the posterior suture. In some cases only the main ribs are present, but often other smaller ribs are intercalated. The type of this species came from Zorritos.

Distribution.—Zorritos Formation of Zorritos, Quebrada Charan, and Quebrada Heath.

Turritella gothica, Grzybowski.

1899. J. Grzybowski, *Neues Jahrb. für Min.* etc., Beil.-Bd. xii. p. 645, Pl. xx. Fig. 10.

A few imperfectly preserved specimens from Grau and Zorritos appear to belong to this species.

Turritella robusta, Grzybowski.

Plate XVIII., Fig. 4. Plate XIX., Fig 1.

1899. *T.* (*Haustator*) *robusta*, J. Grzybowski, *Neues Jahrb. fur Min.* etc., Beil.-Bd. xii. p. 646, Pl. xx. Fig. 3.

This species is represented by portions of a specimen from Zorritos, and another from Quebrada Charan.

Turritella sp., cf. *altilira*, Conrad.

Plate XIX., Figs. 2-4.

Description.—Shell very elongate, of numerous whorls. Each whorl bears two strong rounded spiral ribs at nearly equal distances from the sutures; the summits of these ribs (in well-preserved specimens) bear fine tubercles. The space between the ribs is concave and bears two (sometimes three) fine ribs which are granular. On the last whorl a somewhat smaller rib is present in front of the anterior of the two large ribs, and this is sometimes visible next the suture on the preceding whorls.

Remarks.—The aperture is imperfectly preserved. The species may prove to belong to the sub-genus *Archimediella*, Sacco; it shows a good deal of resemblance to *T. altilira*, Conrad,[1] but the posterior rib is not double as is usually the

[1] A. P. Brown and H. A. Pilsbury, "Fauna of the Gatun Formation," *Proc. Acad. Nat. Sci. Philadelphia*, lxiii. (1911), p. 358, Pl. xxvii. Figs. 2, 3. Syn. *T. Gabbi*, Toula, *Jahrb. k. k. geol. Reichsanst.* lviii., 1908 (1909), p. 695, Pl. xxv. Fig. 5.

case in Conrad's species. *T. altilira* comes from the Miocene of Gatun, Panama.

Distribution.—Zorritos Formation of Quebrada Charan and Quebrada Heath.

Genus Conus, Linnæus.

Conus, sp.

Plate XIX., Fig. 5.

Description.—Height of shell about one and a half times its width. Spire very short, little elevated; its whorls flat or slightly convex, with moderately impressed sutures, and well-marked growth-lines; occasionally with traces of spiral ornament. Last whorl with the shoulder angle inconspicuous and rounded; upper part of whorl becoming flattened or slightly concave towards the aperture; greatest convexity of the whorl in front of the shoulder angle; growth-lines distinct, no spiral ornament seen.

Distribution.—Zorritos Formation of Zorritos and Quebrada Charan.

CHAPTER V

DESCRIPTION OF THE LAMELLIBRANCHIA FROM THE ZORRITOS FORMATION

Genus Scapharca, Gray.

Scapharca zorritosensis, sp. n.

Plate XVIII., Fig. 5.

Description.—Shell of large or moderate size, inequilateral, inflated, rhomboidal, flattened posteriorly. Anterior margin slightly convex; ventral margin slightly curved. Umbones broad, fairly prominent, with a small anterior curvature. Area large, with numerous ligament-grooves. Hinge-line long, with numerous small transverse teeth. Shell ornamented with strong ribs tending to become nodular, separated by broad grooves.

Distribution.—Zorritos Formation, Zorritos.

Genus Crassatellites, Kruger.

Crassatellites charanensis, sp. n.

Plate XIX., Fig. 6. Plate XX., Figs. 1-3.

Description.—Shell large, ovate, narrowing posteriorly, convex between the umbones and the opposite ventral margin, becoming gradually compressed towards the posterior end. Anterior margin rounded; ventral margin moderately convex, sloping upwards to the short posterior margin; postero-dorsal margin slightly concave or nearly straight. Lunule large, elongate-ovate, deeply sunk. Escutcheon narrow, depressed, sharply limited especially near the umbo. A narrow flattened area extends from behind the umbo to

the posterior margin, and becomes indistinctly limited posteriorly. Umbones broad, moderately prominent. To a distance of about 10 mm. from the umbo the shell is ornamented with strong concentric ribs; the remainder of the shell is ornamented with concentric growth-lines which become more prominent anteriorly than elsewhere.

Affinities.—This species approaches *C. kingicoloides*, Pritchard,[1] from Victoria, believed to be of Miocene age, but the umbones are much less elevated and less prominent, and the ornamentation near the umbo is coarser.

Distribution.—Zorritos Formation, Quebrada Charan.

Genus Clementia, Gray.

Clementia sp., cf. *dariena* (Conrad).

Plate XX., Fig. 4.

An internal cast of an imperfect specimen from the Zorritos Formation of Quebrada Charan, resembles closely *Clementia dariena* (Conrad)[2] from the Gatun Formation of Panama. Another similar specimen was obtained from the Zorritos Formation one mile north-east of Boca Pan village.

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[1] *Proc. Roy. Soc. Victoria*, xv. (1902), p. 94, Pl. xiii. Figs. 1-3.

[2] W. M. Gabb, *Journ. Acad. Nat. Sci. Philadelphia* (2), viii. (1881), p. 344, Pl. xliv. Fig. 16. F. Toula, *Jahrb. k. k. geol. Reichsanst.* lviii. (1908), 1909, p. 725, Pl. xxvii. Figs. 9, 10. A. P. Brown and H. A. Pilsbury, *Proc. Acad. Nat. Sci. Philadelphia*, lxiii. (1911), p. 371, Pl. xxviii. Fig. 1.

SECTION B

CRUSTACEA FROM THE EOCENE DEPOSITS OF PERU

By Henry Woods, M.A., F.R.S.

CHAPTER VI

DESCRIPTION OF THE DECAPOD CRUSTACEA FROM THE NEGRITOS AND LOBITOS FORMATIONS

Genus Callianassa, Leach.

Callianassa parinasensis, sp. n.

Plate XVII., Fig. 4.

Description. — Left cheliped: hand nearly oblong, upper and lower margins with sharp edges, the upper curved, the lower nearly straight; external surface of hand evenly convex and apparently smooth, but with a tooth-like projection at the distal end near the base of the movable finger. Fingers about half the length of the hand, both curved inwards; free finger with a tooth near the proximal end, fixed finger apparently without teeth. Carpus equal to the hand in length, upper margin nearly straight, the lower curving upwards at the proximal end; a row of minute and widely separated tubercles occurs near the lower and proximal margins. Merus a little shorter than the carpus, much narrower, especially at the distal end, lower margin very convex. Ischium long, slender, the outer surface with granulations.

Remarks.—This species is represented by four left chelipeds, of which two showing the external surface are fairly well

preserved. *C. Stimpsoni*, Gabb,[1] has been found in the Tejon Group (Eocene) of California[2]; the figures published show only an imperfect hand, but it appears to be quite distinct from the species here described.

Distribution.—Bottom of Lobitos Formation at Punta Parinas.

Callianassa americana, sp. n.

Plate XVII., Figs. 5, 6.

Description.—Hand quadrate and nearly rectangular in outline, its length equal to or rather greater than its breadth. Edge of the upper and especially of the lower margin sharp. Outer surface nearly uniformly convex; inner surface with the middle and upper part convex, the lower part concave, the middle part with numerous small tubercles. Fixed finger slender, sharp, only slightly curved, shorter than the hand. Movable finger stout, with the inner margin sharp and produced into three teeth.

Remarks.—This species appears to be distinct from the forms already known,[3] but is represented only by chelæ (which are numerous), and occasionally by a part of the carpus. It resembles in form *C. Scotti*, Brown and Pilsbry,[4] from the Gatun formation (Miocene) of Panama.

Distribution.—Turritella Series and Clavilithes Series, around Negritos; a portion of a chela (probably of this species) from the Lobitos Formation, one mile south of Talara.

Genus Xanthopsis, M'Coy.

Xanthopsis errans, sp. n.

Plate XVII., Figs. 7-10.

Description.—Carapace transversely oval, broader than long, considerably convex from front to back, moderately from side to side. Lobes not distinctly limited, but broad

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[1] *Geol. Surv. California Palæont.* i. (1864), p. 57, Pl. IX. Fig. 1; ii. (1869), p. 127, Pl. XIX. Fig. 3.

[2] Heilprin, *Contrib. Tert. Geol. and Pal. U.S.* (1884), p. 102. Stanton, "Faunal Relations Eoc. and Upper Cret. Pacific Coast," *17th Ann. Rep. U.S. Geol. Surv.* (1896), p. 1030.

[3] A list of fossil species of *Callianassa* is given by Bohm, *Zeitschr. Deutsch. Geol. Gesellsch.* lxiii. (1911), *Monatsber.* p. 42.

[4] *Proc. Acad. Nat. Sci. Philadelphia*, lxiv. (1912), p. 503, Pl. XXII. Figs. 1-3.

deep depressions bound laterally the cardiac and posterior gastric regions and broaden out posteriorly. The nodules on the protogastric region are only slightly raised; the one on the mesogastric region is a little more distinct; the urogastric nodule is more elevated and is near the mesogastric; on the cardiac region there are two prominent nodules, of which the anterior is about midway between the urogastric and the posterior cardiac nodule. Inner epibranchial nodule large, near the urogastric nodule; outer epibranchial nodule smaller, farther forward, about half-way between the inner nodule and the antero-lateral margin. Mesobranchial nodule small but prominent, almost in a direct posterior line with the outer epibranchial nodule. Metabranchial nodule large, prominent, near the posterior margin but not quite so far back as the posterior cardiac nodule.

Antero-lateral margins regularly convex, rather longer than the postero-lateral margins, with three lateral spines, of which the posterior is prominent and pointed, the middle one smaller, and the anterior one small and inconspicuous; sometimes in front of this is an indication of a fourth spine. Orbits rounded, with a spine-like projection externally. Front projecting forwards, with four prominent teeth, of which the two inner are nearer together and rather more prominent than the two outer. Surface of carapace finely punctate.

The upper margin of the hand of the right cheliped bears a row of about six small tubercles; external to this row is a shallow furrow limited by a slight ridge, which in places is tuberculate. Outer surface of hand convex, with four conspicuous tubercles; one on the distal part at the level of the division between the fixed and movable fingers, the other three on the posterior third forming an oblique row parallel to the posterior proximal border of the hand. Fingers with rounded teeth.

Affinities.—This species belongs to the group which includes *Xanthopsis Leachi* (Desm.), *X. nodosa*, M'Coy, *X. Dufouri*, M.-Edw., *X. unispinosa*, M'Coy, *X. tridentata* (Meyer), and *X. sonthofenensis* (Meyer). A. Milne-Edwards [1] was inclined to regard all of these as varieties of one species, *X. Leachi*. Of the forms mentioned the species now described approaches most nearly to *X. Dufouri*, Milne-Edwards,[2]

[1] *Hist. Crust. Podophthal. Fossiles*, I. (1861–65), p. 270. [2] *Ibid.* p. 255, Pl. XIV.

from the Lower Lutetien of Saint Sever (Landes); the chief points of difference are: the carapace is relatively broader, the urogastric nodule is a little more posterior in position, the outer epibranchial nodule is farther forward and farther from the antero-lateral margin, and the mesobranchial nodule is farther from the postero-lateral margin.

Miss Rathbun [1] states that specimens of an undescribed species of *Xanthopsis* have been found in the Eocene of Alabama, and she has recently described a new species from the Eocene of St. Bartholomew, West Indies.[2] With these exceptions, no example of this genus, which is so common in Europe, appears to have been hitherto recorded from the Eocene deposits of North or South America.

Distribution.—The "Crab Bed," in the Clavilithes Series, about 1000 feet above the base, one mile east of Negritos.

Genus Thaumastoplax, Miers.

Thaumastoplax eocenica, sp. n.

Plate XVII., Fig. 11.

Description.—Carapace rather more than one and a third times as broad as long; very convex from front to back, slightly convex from side to side; sides with sharp edges; regions not defined. Orbits nearly as wide as the front. Antero-lateral margin forming a regular curve; postero-lateral margin slightly curved; posterior margin nearly straight. A curved lateral furrow is seen on each side of the middle of the carapace a little behind the centre; between the furrows in front are two elongate oblique tubercles, and behind are two small rounded tubercles. Chelipeds short and stout.

Remarks.—Only one specimen of this species has been found; most of the carapace has been lost, leaving an internal cast. The chelipeds are fairly preserved, and a portion of one of the walking legs on the left side.

This species is provisionally referred to the genus *Thaumastoplax* (Family Goneplacidæ) on account of the close resem-

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[1] *Bull. Geol. Soc. America*, xiii. (1902), p. 44.

[2] "W. Indian Tert. Decapod Crustaceans," *Carnegie Inst. Publ.* 291 (1919), p. 176, Pl. viii. Fig. 3.

blance in the form of the carapace to that of the type species; the specimen gives no indication of the number of the walking legs, but the shortness of the carapace suggests that only three were present. The type of *Thaumastoplax* (*T. anomalipes*, Miers [1]) is in the British Museum (Natural History), and through the kindness of Dr. W. T. Calman I have been able to compare it with the fossil form. A specimen from the Culebra Formation (Oligocene) of the Panama Canal zone has been referred by Miss M. J. Rathbun [2] to the *Thaumastoplax*, but it does not resemble the type species so closely as does the specimen here described.

Distribution.—The " Crab Bed " in the Clavilithes Series about 1000 feet above the base, one mile east of Negritos.

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[1] E. J. Miers, *Ann. Mag. Nat. Hist.* (5), viii. (1881), p. 261, Pl. xiv. Fig. 2.
[2] *Bull. U.S. Nat. Mus.*, 103 (1918), p. 176, Pl. lxvi., Figs. 15-18.

SECTION C

AN ECHINOID FROM THE EOCENE DEPOSITS OF PERU

By Herbert L. Hawkins, D.Sc.

CHAPTER VII

A NEW SPECIES OF ECHINOID FROM THE LOBITOS FORMATION

Five small Echinoids from the Lobitos Formation of Peru were sent me for examination. These were collected near Punta Parinas, from a seam just above a Crustacea Bed, near the base of the Lobitos Formation. They are quite free from matrix (except internally), but have lost almost all their surface detail through weathering. They seem all to belong to one species. One specimen (No. 2) has been dissected in an endeavour to determine its generic position, but crumbling of the test made the attempt unsuccessful. On most external evidence the forms belong to *Echinocyamus*, but it was impossible to recognise with certainty either the perignathic girdle or radiating partitions in the specimen broken. If the latter features are really absent, the form would be more of a *Fibularia*; but the flatness of the test makes

this unlikely. I therefore prefer to regard it provisionally as a species of *Echinocyamus*, which cannot be referred to any described type with which I am acquainted. In spite of the indifferent preservation of surface features, there seems enough evidence to diagnose a new species.

"*Echinocyamus*" *intermedius*, sp. n.

Five specimens (one destroyed), of which No. 1 is selected as holotype.

	Dimensions in millimetres.		
	Length.	Breadth.	Height.
No. 1 (type) . . .	5·6	4·9	2·4
No. 2 (destroyed) . .	5·3	4·7	2·2
No. 3	5·1	4·4	2·1
No. 4	4·5	4·1	2·0
No. 5 (broken) . .	4·2 ?	4·1	2·1

Breadth of holotype ·875 of length.
Height ,, ,, ·43 ,, ,,

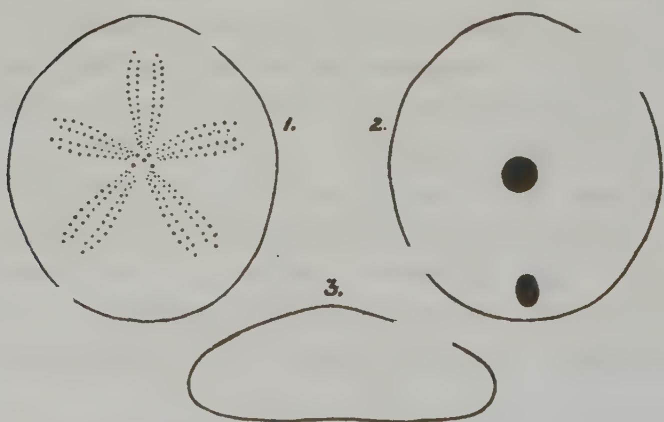

Fig. 25.—"*Echinocyamus*" *intermedius*. 1. Adapical plan. 2. Adoral plan. 3. Profile (anterior end on left).

Diagnosis (based on holotype alone).—Ambitus ovoid, projecting anteriorly, rounded posteriorly, obscurely subpentagonal. Adapical surface forming a depressed pyramid rising to a central apex. Adoral surface almost flat, slightly tumid along the radii. Ambital angle acute, but well rounded.

Peristome practically central, very slightly posterior, almost circular, faintly subpentagonal, with diameter of about ·75 mm.; scarcely invaginate.

Periproct just below the margin, about 1·4 mm. from peristome, elliptical longitudinally, small.

Apical system central, not specially prominent. Four genital pores, the posterior pair more widely separated than the anterior. Single madreporic pore just behind the line joining the anterior genital pores; equidistant from the latter.

Petals strongly marked; similar, except for III., which is slightly longer and narrower than the others, and includes more pore-pairs. Inner row of pores almost straight, outer arcuate. Pores of each pair strongly oblique, especially in III. Extra-petaloid pores not seen.

No continuous sutures appear on the corona. Traces of ornament preserved near the peristome indicate proportionately coarse tuberculation.

Discussion.—The four other specimens agree in all essentials with the above diagnosis, but in some the periproct is extremely minute. Comparison of the measurements given shows that elongation of the test increases with size—this is chiefly due to extension of the anterior region.

The most striking characteristics of "*E.*" *intermedius* are the approximation of the small periproct

to the margin, and the unusually elaborate nature of the petals. Both qualities make reference of the species to *Echinocyamus* doubtful, and certainly distinguish it from all other members of the genus. The appearance of the adoral surface is far more like that of a *Laganum* than of an ordinary Fibulariid. The petals comprise far more pore-pairs than is usual in *Echinocyamus*, and the individual pores are relatively small. The most obvious feature here, however, is the extreme obliquity of the pore-pairs. The obliquity increases distally in each petal, so that in the outermost pairs the pores are almost superposed. The petals are comparable with reduced Scutellid types—they show a great advance on the structure normal to the Fibulariidæ.

While recognising that this species shows at least two important differences from *Echinocyamus*, I have thought it best to place it in that genus provisionally. The morphology and classification of the smaller Clypeastroida are much in need of revision, but the five specimens here described do not lend themselves, either externally or internally, to satisfactory generic determination. As far as the evidence goes, they appear to hover on the borders of the three families Fibulariidæ, Scutellidæ, and Laganidæ.

Since there are no species of *Echinocyamus* (nor of any other genus) with which "*E.*" *intermedius* can reasonably be compared, no satisfactory indications of the horizon from which it came are available. The periproct is in a morphogenetically "early" position, but the petals are yet more definitely "late." It is to be hoped that more material of this small Echinoid may be procured, for it appears likely that

it might, when better known, throw much light on the relations of most Clypeastroid families. Its synthetic qualities tend to suggest an earlier, rather than a later, time for its appearance, but no greater precision in this matter is possible.

SECTION D

CORALS FROM THE EOCENE DEPOSITS OF PERU

By T. Wayland Vaughan, Ph.D.[1]

CHAPTER VIII

THE CORALS OF THE NEGRITOS FORMATION AND THEIR RELATIONSHIP

A small collection of fossil corals from Peru, made by Dr. T. O. Bosworth, has been submitted to me for study. All the specimens were obtained from the Negritos Formation at various spots within two miles of Negritos.

The following is a table of the species :

Eocene Corals from the Negritos Formation of Peru.

Species.	Turritella Series.	Clavilithes Series.
Paracyathus peruvianus, Vaughan, sp. n. .	. .	×
Oculina peruviana, Vaughan, sp. n. . .	. .	×
Peruviastrea peruviana, Vaughan, new gen. and sp.	. .	×
Haimesiastræa peruviana, Vaughan, sp. n. .	×	×
,, *humilis*, Vaughan, sp. n. .	×	×
,, *distans*, Vaughan, sp. n. .	×	×
Stephanocœnia peruviana, Vaughan, sp. n. .	×	×
Dendrophyllia peruviana, Vaughan, sp. n. .	. .	×

[1] Published by permission of the Director of the United States Geological Survey. The illustrations for the paper were furnished by the United States Geological Survey.

After the description a few notes are given on the general relations of those species that are similar to species previously recorded from American Tertiary formations. As an aid in geologic correlation the species of *Haimesiastræa*, to which I am applying the name *H. peruviana*, is particularly significant. *H. peruviana* is doubtfully separable from *H. conferta* Vaughan from the Wilcox and Midway Eocene of Alabama, and on the basis of its presence I am led to infer that the beds containing these corals are a little older than the Claiborne group of the south-eastern United States, and that they correspond in age to the middle or to the upper part of the Wilcox group,[1] which is about the stratigraphic equivalent of the Ypresian of Europe. *H. peruviana* suggests that there may have been connection during Eocene time between the Atlantic and Pacific Oceans across Central America prior to the Lutetian stage. A species of *Haimesiastræa*, *H. petrosa* (Gabb) Vaughan,[2] from California is in accord with this suggestion.

[1] For general correlation of the Tertiary formations of eastern North America, etc., see T. W. Vaughan, "Correlation of the Tertiary Geologic Formations of the South-Eastern United States, Central America, and the West Indies," *Washington Acad. Sci. Jour.* vol. viii. pp. 268-276 (1918); "The Biologic Character and Geologic Correlation of the Sedimentary Formations of Panama in their Relation to the Geologic History of Central America and the West Indies," *U.S. Nat. Mus. Bull.* 103, pp. 547-612 (1919); "Cenozoic History of Central America and the West Indies," *Bull. Geol. Soc. Amer.* vol. xxix. pp. 138, 615 (1918), 1919.

[2] For a detailed description of the type specimen of this coral, see T. W. Vaughan, "Eocene and Lower Oligocene Coral Faunas of the United States," *U.S. Geol. Survey Mon.* 39, pp. 146-148, Pl. xvii. Figs. 1-6 (1900). Without giving the basis of his opinion, J. O. Nomland in his "Corals from the Cretaceous and Tertiary of California and Oregon," *Univ. Calif. Publ.* vol. ix. p. 60 (1916), lists *Haimesiastræa petrosa* as of Cretaceous age. In my paper above cited I have stated the conditions under which the type was collected. Until additional material has been obtained in definitely known stratigraphic relations, there will be doubt as to the stratigraphic position of *H. petrosa*. From present information it appears probable that the type came from the lower Eocene Martinez group.

CHAPTER IX

DESCRIPTION OF THE SPECIES OF CORALS FROM THE NEGRITOS FORMATION

Genus Paracyathus, Milne-Edwards and Haime.

Paracyathus peruvianus, Vaughan, sp. n.

Plate XXI., Figs. 1, 1*a*, 1*b*, 1*c*.

Description of Holotype.—Corallum inversely conical, slightly compressed, a little curved in the plane of the shorter calicular axis, attached by a small area at the apex. Height, 14 mm.; 8 mm. above the base the diameter is 9·25 by 10 mm.; depth of calice, measured from upper edge of wall, on the convex side of the corallum to the bottom of the calicular fossa, about 7 mm.

Wall rather stout, thickened by internal stereoplasmic deposit, externally costate. Costæ correspond to all septa, over most of the outer surface they strongly alternate in size, a few more than 20 (about 24) extend to or very nearly to the basal scar. Higher up on the corallum, as a rule, a smaller costa is introduced between each pair of larger ones, and between a few pairs of the larger, two or three smaller costæ are introduced. The alternation in size of the costæ is much more pronounced on the convex than on the concave side of the corallum. Costal edges rather sharp on the convex curvature, most of them obtusely rounded on the concave curvature of the corallum. Costal bases rather wide, intercostal furrows narrow at the bottom. Fine granulations over the costal surfaces.

There are a few more than four complete cycles of septa. Margins of the members of the first three cycles moderately

prominent project from about 1 to 1·5 mm. above the wall; margins of the tertiaries not so tall.

Pali well developed, in two or more crowns, probably present before all except the last cycle of septa; appear to become confused with the columellar papillæ in the manner characteristic of *Paracyathus*.

Columella, as usual in the genus.

Locality and Geologic Occurrence.—¾ mile south-east of Negritos, lower part of Clavilithes Series.

I am referring this coral to the genus *Paracyathus*, although I have not been able to work out the palar characters in so much detail as I should like to do. *P. peruvianus* seems to be only a large variety of *Paracyathus alternatus*, Vaughan,[1] from the Claibornian Lisbon formation in Mississippi and the stratigraphically equivalent formations in Louisiana and Texas; but, as I have seen no specimen of *P. alternatus* (and there are hundreds of specimens in the United States National Museum collections) that is so large as the holotype of *P. peruvianus*, they appear to be closely related but distinct species. Mention should also be made of the general similarity of *P. peruvianus* to *Trochocyathus speciosus* (Gabb and Horn), Vaughan,[2] from the Midwayan Lower Eocene of Hardeman County, Tennessee.

Genus Oculina, Lamarck.

Oculina peruviana, Vaughan, sp. n.

Plate XXI., Figs. 2, 3, 4, 5.

Description based on Four Cotypes.—Corallum composed of irregularly shaped, more or less contorted branches, among which there is some anastomosis. The cross section of the branches is subelliptical or subquadrangular. Measurements of the diameters of several branches are as follows: 5 by 7 mm., 7·5 by 8·5 mm., 9 by 11 mm. Large branches exceed

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[1] T. W. Vaughan, "Eocene and Lower Oligocene Coral Faunas of the United States," *U.S. Geol. Survey Mon.* 39, pp. 105-107, Pl. VIII. Figs. 11-14*b*, 1900.

[2] T. W. Vaughan, "A Redescription of the Coral *Platytrochus speciosus*," *Washington Biolog. Soc. Proc.* vol. xv. pp. 207-209, text-figs. 1, 1*a*, 1*b*, 2, 2*a* (1902).

10 mm. in maximum diameter. The height of an entire corallum is not known.

Calicular margins either flush with the cœnenchymal surface, very slightly raised, or protuberant as much as 2 mm.; they are more prominent, as is usual in *Oculina*, on the younger than on the older parts of branches. The sides of the free corallite limbs rise steeply from the cœnenchyma and decrease very little in diameter between the base of the free limb and the calicular aperture. Costæ are distinct only around the calicular margin. Diameter of calices, from 2·5 to 3 mm.; depth, 2 mm.; distance apart, from 3 to 7·5 mm., considerable areas are devoid of calices.

Septa, 24 in number, 3 cycles recognisable; primaries and secondaries reach the columella, but they are narrow in the upper part of the calice, the primaries stand a little higher than the secondaries; tertiaries narrow. Distinct paliform lobes on the inner ends of the primaries and secondaries.

Columella false but well developed, composed of interfused processes from the inner ends of the principal septa; upper surface coarsely papillate.

Cœnenchyma absolutely solid, marked by longitudinal striations. Costæ correspond to all septa but are confined to the peripheries of the calices; they are low, rather acute, and subequal.

Locality and Geologic Occurrence.—Near Negritos; Clavilithes Series.

Genus Peruviastrea, Vaughan, new genus.

Peruviastrea is proposed as the generic name of the species next described, *Peruviastrea peruviana*, the only representative of the genus at present known. The growth form of the type species is ramose; asexual reproduction is by intercalicular gemmation; the calices are circular or subcircular in outline; the septal margins are entire, and there are on the faces of the larger septa lateral wings similar to those on the sides of the septa of *Haimesiastræa*; the columella is a prominent, stout, erect, compressed axial style. In the type species the cœnenchyma seems solid, and the corallite cavities appear solidly filled with stereoplasm, but some of this compactness of structure may be due to secondary changes. Dissepiments are present.

Peruviastrea is closely related to *Haimesiastræa*, differing from that genus chiefly by its possession of a prominent, compressed, styliform columella.

PERUVIASTREA PERUVIANA, Vaughan, sp. n.

Plate XXI., Figs. 6, 6*a*, 7, 7*a*.

Description of Cotypes.—The cotypes are fragments of two branches. Corallum ramose; branches broadly elliptical or strongly compressed in cross section. The larger cotype is 31·5 by 27 mm. in diameter at its lower end. The smaller cotype is composed of an axial branch from which there was a lateral branchlet on each side; the axial branch is about 10 by 8 mm. in diameter at its lower end and about 9 by 7·5 mm. at its upper end; the scars where the lateral branchlets were broken off are respectively 17·5 by 8·5 mm. and 12 by 8 mm. in diameter.

The calices of the smaller cotypes are subcircular or very broadly elliptical in plan; margins very slightly or not at all elevated, about 0·4 mm. a very unusual maximum height, as a rule less than 0·25 mm. high. Maximum diameter, 1·75 by 1·4 mm.; small calices 1·1 mm. in diameter—range in diameter from 1·1 to 1·75 mm., 1·25 mm. about the average. Distance apart from a stout, but narrow, dividing wall up to 1 mm.; 0·6 mm. usual, or the usual distance apart is approximately one-half the calicular diameter. Depth about 0·75 mm. The calices of the larger cotype are usually about 1·5 mm. in diameter, and they average 1 mm. or a little more apart; the maximum distance apart may be as much as 1·5 mm.

The septa are normally in three complete cycles. The primaries are rather thick, they project far into the calicular cavity above the calicular floor, their inner edges fall perpendicularly to the periphery of the columellar pit, and low down in the calice they join the columella. The secondaries are neither so prominent nor so thick as the primaries, but they extend to the columella, around which their inner ends may be distinctly thickened. The tertiaries are shorter and thinner, and have a tendency to fuse to the sides of the included secondary septum. Septal margins entire or microscopically dentate. I was not able to distinguish any dentations. The

faces of many primaries and secondaries have near the inner septal edges winglike expansions similar to those in *Haimesiastræa.* In some calices there appear to be paliform lobes around the columella on the inner ends of the primaries and secondaries, but there are no clear-cut palar crowns.

The upper septal margins are not prominent but are continued into low, rather wide, subequal costæ, which may or may not be traceable across the surface of the very finely granulate intercorallite cœnenchyma. Corallite cavities seem to be solidly filled with stereoplasm.

Columella, a stout, prominent, erect, blunt, strongly compressed style, which in worn calices appears as solid columella plug.

Dissepiments are present. The cœnenchyma appears solid, but some of the compactness may have been caused by secondary changes.

Locality and Geologic Occurrence.—Near Negritos; Clavilithes Series.

Genus HAIMESIASTRÆA, Vaughan.

Haimesiastræa peruviana, Vaughan, sp. n.

Plate XXII., Figs. 2, 2*a*, 2*b*.

Description of Holotype.—The holotype is the terminal part of a branch, 18 mm. long and 9·5 by 11 mm. in diameter in constriction just below summit bifurcation. The corallum therefore is ramose; branches subcircular or broadly elliptical in cross-section, except at the base of bifurcation where there is lateral compression; branch summits obtusely rounded.

Calices excavated but rather shallow, subcircular or broadly elliptical in outline; margins very slightly or not at all protuberant; separated by flat, costate, intercorallite areas, in the middle of which there is in many places a low, rather narrow, intercorallite ridge. Diameter, from 1·5 to 2 mm.; depth, about 0·75 mm.; distance apart, from about 0·25 up to 1·5 mm., usually about 0·6 mm.

Septa rather thin, normally in three complete cycles; primaries slightly the largest and most prominent, extend to calicular centre; secondaries slightly smaller than the primaries, but they as a rule reach the calicular centre; tertiaries short and thin. Septal margins entire. Upper

edges of the primaries and secondaries slightly exsert at the wall, those of the tertiaries less prominent. All septa are a little thickened in the wall, and beyond it in the intercorallite areas costæ correspond to them. The costæ are low, usually thin, and extend to the intercorallite ridge. Within the calices the larger septa may extend a short distance as plates and then drop steeply to the bottom of the calice, or they may slope, with or without upwardly concave curvature near the wall, to the centre of the calice. In some calices there is around the calicular centres an elevated lobe on each of some of the longest septa, but the lobes do not form a definite, persistently present palar crown. Septal faces appear entirely devoid of granulations. The primary and secondary septa have winglike projections on their sides near their edges precisely as in *Haimesiastræa conferta*, the type-species of the genus.

There is no columella, but the inner ends of the long septa meet along the axis of the corallite, and below the calicular floor they are cemented together by secondary stereoplasmic deposit.

Thin endothecal dissepiments highly developed; exothecal dissepiments present between the costæ, but to a considerable degree the exotheca is solid stereoplasmic deposit, as in the genotype. The branch axes are more or less spongy as the corallite cavities are not solidly filled.

Localities and Geologic Occurrence.—Near Negritos, Turritella Series (holotype); also Clavilithes Series.

H. peruviana is so very similar to *H. conferta* (*see* Plate XXII., Figs. 1, 1*a*) that specific difference is doubtful; however, because on branch terminals the calices of *H. conferta* are deeper and the calicular cavities more funicular than in *H. peruviana*, two species seem distinguishable.

Haimesiastræa humilis, Vaughan, sp. n.

Plate XXII., Figs. 3, 3*a*, 4, 4*a*.

Description of Holotype.—Holotype, the broken lower part of a corallum which is attached to and partly invests a piece of greenish sandstone. Corallum ramose, branches subterete; cross-section of branch is 14·5 by 14 mm. in diameter.

Calices excavated, rather shallow, subcircular or broadly

elliptical in outline; margins flush with the surface of the intercorallite areas or very slightly raised; separated by flat, costate, intercorallite areas, in the middle of which there may be an obscure intercorallite ridge. Diameter, 1·75 to 2 mm.; depth, about 0·7 mm.; distance apart, from 0·4 to 2·75 mm., about 1·2 mm. usual.

Septa normally in three complete cycles; similar in their general features to the septa of *H. peruviana*. Costæ on the intercorallite areas strong.

There is no columella; the principal septa meet below the bottom of the calices as in other species of the genus.

Description of Paratype.—This is a terminal branchlet, 32 mm. long and 6 by 7 mm. in diameter at its lower end.

Calices with margins flush with the intercorallite areas; 2·25 mm. in diameter; separated by strongly costate intercorallite areas which are usually a little more than 1 mm. across.

Localities and Geologic Occurrence.—Near Negritos, Turritella Series (holotype and paratype); Clavilithes Series, a much damaged specimen that seems to belong to this species.

H. humilis is immediately separable from *H. distans*, the description of which follows, by its non-exsert calicular margins, its less distant calices, and its more strongly costate intercorallite areas. It is separable from *H. peruviana* by its more attenuate branches, larger and more distant calices, and its more strongly costate intercorallite areas.

Haimesiastræa distans, Vaughan, sp. n.

Plate XXII., Figs. 5, 5*a*.

Description of Holotype.—Corallum ramose, branches subcircular in cross-section. Diameter of broken lower end, 18·5 by 16 mm.; diameter of broken ends of branches on upper part of specimen from 6 by 5·5 mm. to 9·5 by 8·5 mm.

Calices subcircular, rather small, with elevated rims, separated by wide interspaces. Diameter about 1·6 mm.; protuberant from 0·5 to 1 mm.; depth, 0·75 mm. or a little more; distance apart, from 1·25 to 3 mm. Free corallite limbs marked by thick, rather low, subequal or alternately larger and smaller, very finely granulate costæ.

Septa in three cycles. The primaries are the thicker, and

extend to the calicular axis; secondaries almost as large, and extend to or almost to the centre; tertiaries smaller, tend to fuse to the sides of the secondaries. The outer ends of all septa are thickened in the wall. Primaries and secondaries moderately prominent over the wall; tertiaries low; costæ correspond to all septa. Septal margins appear entire. Faces of primaries and secondaries with winglike expansions near their inner edges as in other species of *Haimesiastræa.*

Coenenchyma solid. Corallite cavities become solidly filled with stereoplasm.

There is no columella, no vestige of one is seen in well-preserved calices; but it is probable that the inner ends of the longer septa meet and fuse below the level of the calicular floor.

Locality and Geologic Occurrence.—Near Negritos, Clavilithes Series.

Genus STEPHANOCŒNIA, Milne-Edwards and Haime.

Stephanocœnia peruviana, Vaughan, sp. n.

Plate XXIII., Figs. 1, 1*a*, 2, 2*a*.

Description of the Holotype.—Corallum forming a rather small rounded mass with irregular tuberosities on the surface. Maximum diameter about 66 mm.; lesser diameter about 58 mm.; thickness about 45 mm.

Calices shallow, polygonal; usually separated by narrow walls, but in places there are costate intercorallite areas that may be as much as 1 mm. across. Diameter of calices from 1·5 to 2·5 mm., one of the diameters in most calices somewhat longer than the other; depth about 0·3 mm., somewhat more in some calices.

Septa moderately thick, normally in three complete cycles; the primaries somewhat the most prominent and extend to the columella; secondaries slightly less prominent than the primaries and as a rule reach the columella; tertiaries shorter than the secondaries, to the sides of which they fuse by their inner edges. The septal margins are low at the wall, and where costæ are present they are not conspicuous. Within the calices the septal edges either fall steeply close to the wall to near the level of the floor of the calice or they slope gradually from the top of the wall to their inner ends. The septal

edges are very finely dentate; the septal faces bear some rather coarse granulations.

There are distinct, rather wide pali on the inner ends of both the primary and secondary septa.

Dissepiments are well developed. In most calices, even where the calices are separated by narrow walls, they can be recognised near the level of the wall; in some calices they form a shelf on each side of the wall, which there can be traced as a low wall-ridge. Lower down in the calices thin dissepiments reach from the wall to the columella.

Columella, a compressed, moderately prominent axial style.

Locality and Geologic Occurrence.—Near Negritos, Clavilithes Series (the holotype); also Turritella Series, and lower part of Lobitos Formation, around Negritos.

The specimen from the Turritella Series has calices as much as 1 mm. deep, and the pali are not so well developed as in the specimens with shallower calices.

The presence of dissepiments so high up in the calice and the slope of these dissepiments downward toward the corallite peripheries result in the appearance of a synapticular zone near the wall; but, as I was able to discern that most of the structures were the exposed edges of dissepiments, the inference seems warranted that only dissepiments are present. The upper surface of specimens of *Stephanocœnia intersepta*, the type species of the genus, presents a similar appearance, but longitudinal sections of the corallites reveal only dissepiments.

Genus DENDROPHYLLIA, de Blainville.

Dendrophyllia peruviana, Vaughan, sp. n.

Plate XXIII., Figs. 3, 3*a*.

Description of Holotype.—Holotype, a segment of branch; it is 22 mm. long, 7·5 mm. in diameter at the lower end, 6·5 mm. in diameter at upper end. Growth form of the corallum is ramose, with an axial master polyp.

Calices elliptical in cross-section, roughly spiral in arrangement, elevated as much as 3·5 mm. above the cœnenchyma, from 3 to 4·5 mm. apart. The free corallite limbs make an angle of about 140 degrees with the cœnenchymal surface at

the lower foot of the limb; upper angle of the corallite limb about 40 degrees. Gradual, slight decrease in diameter from the base of the corallite limb to the calicular aperture. Diameter of normal adult calice, 3 by 4 mm.

As the septa are damaged, their number can be determined only by counting the costæ. They range from 24 to over 30, 33, or 34. That there is the usual dendrophylliid septal arrangement is obvious although the septal details are not revealed. The costæ are coarse, more or less vermiculate, summits rather sharp, in places stout synapticulæ between the costæ.

Columella distinct, moderately large.

Cœnenchyma ultimately becomes solid, and the corallite cavities are filled to near the surface with stereoplasmic deposit.

Locality and Geologic Occurrence.—Near Negritos, Clavilithes Series.

At first I hesitated to apply a specific name to this specimen, which is only a fragment, but its growth form and the shape, size, degree of prominence, and arrangement of its calices seem to supply adequate criteria for its identification, should it be collected again. *Dendrophyllia lisbonensis*, Vaughan [1] from the Claibornian Lisbon Formation of Alabama and the stratigraphically equivalent upper part of the Saint Maurice Formation in Louisiana, has considerable similarity to *D. peruviana*, but it differs in having smaller calices and smaller, more numerous costæ.

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[1] T. W. Vaughan, "Eocene and Lower Oligocene Coral Faunas of the United States," *U.S. Geol. Survey Mon.* 39, pp. 191-193, Pl. XXII. Figs. 20, 20*a-c* (1900).

SECTION E

FORAMINIFERA FROM THE EOCENE DEPOSITS OF PERU

By J. A. Cushman, Ph.D.

CHAPTER X

FORAMINIFERA FROM THE LOBITOS FORMATION

A very small collection of fossil foraminifera from Peru, made by Dr. T. O. Bosworth, has been submitted to me for examination.

The specimens come from four localities. While the material is not particularly well preserved, it has been possible to work out several of the species, two of them evidently being undescribed.

The species found at two of the localities seem to be definitely Eocene in age: from the Lobitos Formation of Mount Organo comes *Lepidocyclina antillea*, which I recently described from the Eocene of St. Bartholomew, and which also seems to occur in beds of questionable Eocene age, Panama; from the Lobitos Formation around Negritos there is a species of *Orthophragmina*, which places this lot of material definitely in the Upper Eocene.

From the Lobitos Formation of Lagunitas there is a new species of *Lepidocyclina* of the sub-genus *Nephrolepidina*, which is known to occur as high as the Middle Oligocene; and from the Lobitos Formation around Negritos there are a very few poorly preserved specimens of *Lepidocyclina* which suggest *Lepidocyclina antillea.* If this identification is correct it would also place the horizon at this locality in the Upper Eocene.

Notes on the few species obtained follow, together with the figures of a few of them, which are from photographs of the specimens themselves.

List of the Species of Foraminifera examined.

Lepidocyclina antillea, Cushman.—From the Lobitos Formation of Mt. Organo, 7 miles north-east of Cabo Blanco.

Lepidocyclina antillea (?), Cushman.—From the lowest 1000 feet of the Lobitos Formation, around Negritos.

Lepidocyclina (*Nephrolepidina*) *peruviana,* sp. n.—From the Lobitos Formation of Lagunitas.

Orthophragmina peruviana, sp. n.—From the lowest 1000 feet of the Lobitos Formation, around Negritos.

Nummulites, sp.—From the lowest 1000 feet of the Lobitos Formation, around Negritos.

Nummulites, sp.—From the lowest 1000 feet of the Lobitos Formation, around Negritos.

Description of the Species.

Lepidocyclina antillea, Cushman.

Plate XXIV., Fig. 2.

Lepidocyclina antillea, Cushman, *Publication* 291, *Carnegie Instit. Washington,* 1919, p. 63, Pl. III. Fig. 3.

There are a few specimens from the Lobitos Formation of Mt. Organo (7 miles north-east of Cabo Blanco), which seem in their general characters to belong to this species described

from the Eocene of St. Bartholomew, Leeward Islands, and also known from Panama.

Lepidocyclina antillea (?), Cushman.

There are a very few poorly preserved specimens from the Lobitos Formation, around Negritos, which strongly suggest this species. The specimens are small and seem to have fewer pillars than the typical form.

Lepidocyclina (*Nephrolepidina*) *peruviana*, Cushman, sp. n.

Plate XXIV., Fig. 1.

Description.—Test small, circular, biconvex, highest in the central region, thence gradually sloping toward the periphery, where there is a thin flange-like portion merging gradually into the central mass; centre with a few well-developed pillars, seen on the surface as rounded papillæ; peripheral portion, with a few small pillars wanting near the edge; horizontal sections show the equatorial chambers diamond-shape, as is usual in this sub-genus. Diameter, 3 mm. or less.

Specimens of this species are numerous from the Lobitos Formation of Lagunitas. There is one specimen which is peculiar in having a trihedral form, such as sometimes occurs in *Orbitolites*, where one side is flat and the equatorial chambers extend at right angles on the other side, thus forming three distinct faces about the test.

Orthophragmina peruviana, Cushman, sp. n.

Plate XXIV., Fig. 3.

Description.—Test circular, consisting of two portions, the central raised, umbonate, occupying about one-third of the diameter of the test, surrounded by a thin flange-like portion of equal width; surface coarsely papillate, both the centre and the peripheral portion almost equally so. Diameter about 6 mm.

Accidental sections show the very narrow rectangular chambers of the equatorial region. This species reminds one

of *Orthophragmina marthæ*, Schlumberger (*Bull. Soc. géol. France*, Ser. IV. vol. iii., 1903, p. 284, Pl. X., Figs. 27-29, 32; Pl. XI., Figs. 39, 40).

In our species the granulations are in greater number, and the test itself is much smaller. The specimens are from the Lobitos Formation, around Negritos.

Nummulites, sp. (?)

From the Lobitos Formation around Negritos there are numerous specimens with small *Nummulites*, 2 to 3 mm. in diameter, and much flattened, and also from the Lobitos Formation of the same district another species, also small and apparently biconvex.

EXPLANATIONS OF PLATES I.-XXIV.

The figures are of natural size unless the amount of enlargement is stated. Different views of the same specimen bear the same number with letters *a, b, c,* etc. The specimens figured are in the Sedgwick Museum, Cambridge

PLATE I.

Figs. 1-3.—*Leda ingens*, sp. n. Turritella Series, near Negritos. Figs. 1, 2, Right valves. Fig. 3, Dorsal view. ×1½. (P. 61.)

Fig. 4.—*Barbatia*, sp. Turritella Series, 1 mile east of Negritos. Left valve ×1½. (P. 62.)

Fig. 5.—*Scapharca (Argina) sullanensis*, sp. n. Lobitos Formation, 10 miles W.N.W. of Sullana. *a*, Left valve; *b*, dorsal view. (P. 62.)

Figs. 6, 7.—*Mytilus euglyphus*, sp. n. Right valves. Fig. 7*b*, Antero-ventral view of 7*a*. Clavilithes Series, near Negritos. ×1½. (P. 63.)

Fig. 8.—*Mytilus euglyphus?* Turritella Series, near Negritos. Left valve. ×1½. (P. 63.)

Fig. 9.—*Ostrea Inca*, sp. n. Clavilithes Series, near Negritos. *a*, Left valve; *b*, right valve; *c*, posterior view. (P. 64.)

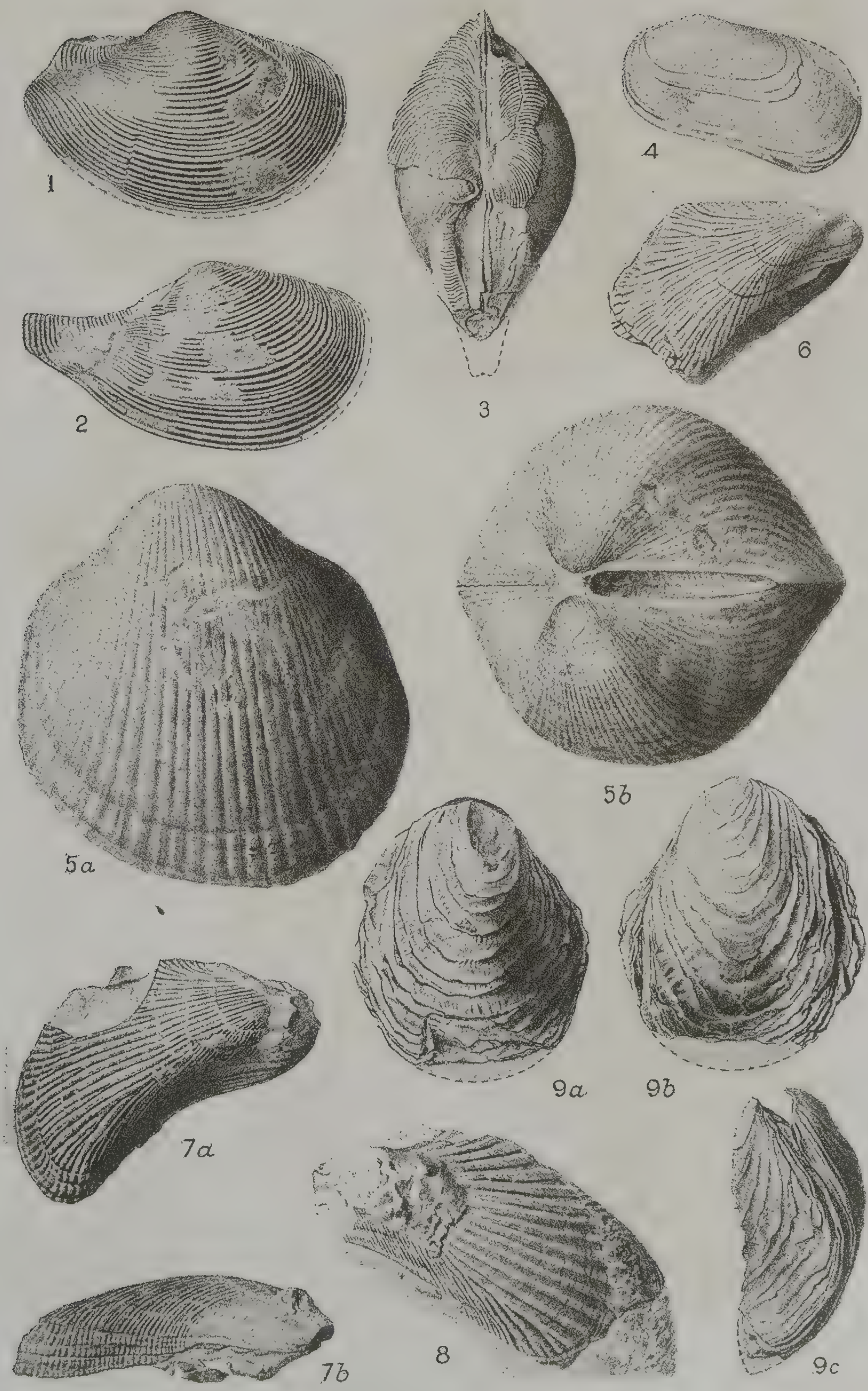

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PLATE II.

Figs. 1, 2.—*Ostrea Inca*, sp. n. Clavilithes Series, near Negritos. Fig. 1, Right valve. Fig. 2, Posterior view. (P. 64.)

Figs. 3, 4.—*Ostrea Buski*, sp. n. Turritella Series, near Negritos. Left valves. Fig. 4*b*, Posterior view of 4*a*. (P. 65.)

Fig. 5.—*Ostrea*, sp. Turritella Series, near Negritos. Left valve. (P. 65.)

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PLATE III.

Fig. 1.—*Perna arbolensis*, sp. n. Parinas Sandstone, east of Negritos. Left valve. (P. 65.)

Figs. 2, 3.—*Venericardia planicosta*, Lamarck (group). Fig. 2, Clavilithes Series, near Negritos. Fig. 3, Parinas Sandstone, near Negritos. Left valves. (P. 66.)

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PLATE IV.

Figs. 1-3.—*Venericardia planicosta*, Lamarck (group). Fig. 1, Right valve, Turritella Series, near Negritos. Fig. 2, Right valve, Clavilithes Series, near Negritos. Fig. 3, Right hinge, Lobitos Formation, 10 miles W.N.W. of Sullana. (P. 66.)

Fig. 4.—*Venericardia*, sp. Right valve. Turritella Series, near Negritos. (P. 69.)

Fig. 5.—*Lucina paytensis*, sp. n. Lobitos Formation, Payta. *a*, Right valve; *b*, dorsal view; *c*, ornamentation ×3. (P. 70.)

Fig. 6.—*Callista* (*Macrocallista*) *Dickersoni*, sp. n. Clavilithes Series, near Negritos. *a*, Right valve; *b*, dorsal view. (P. 71.)

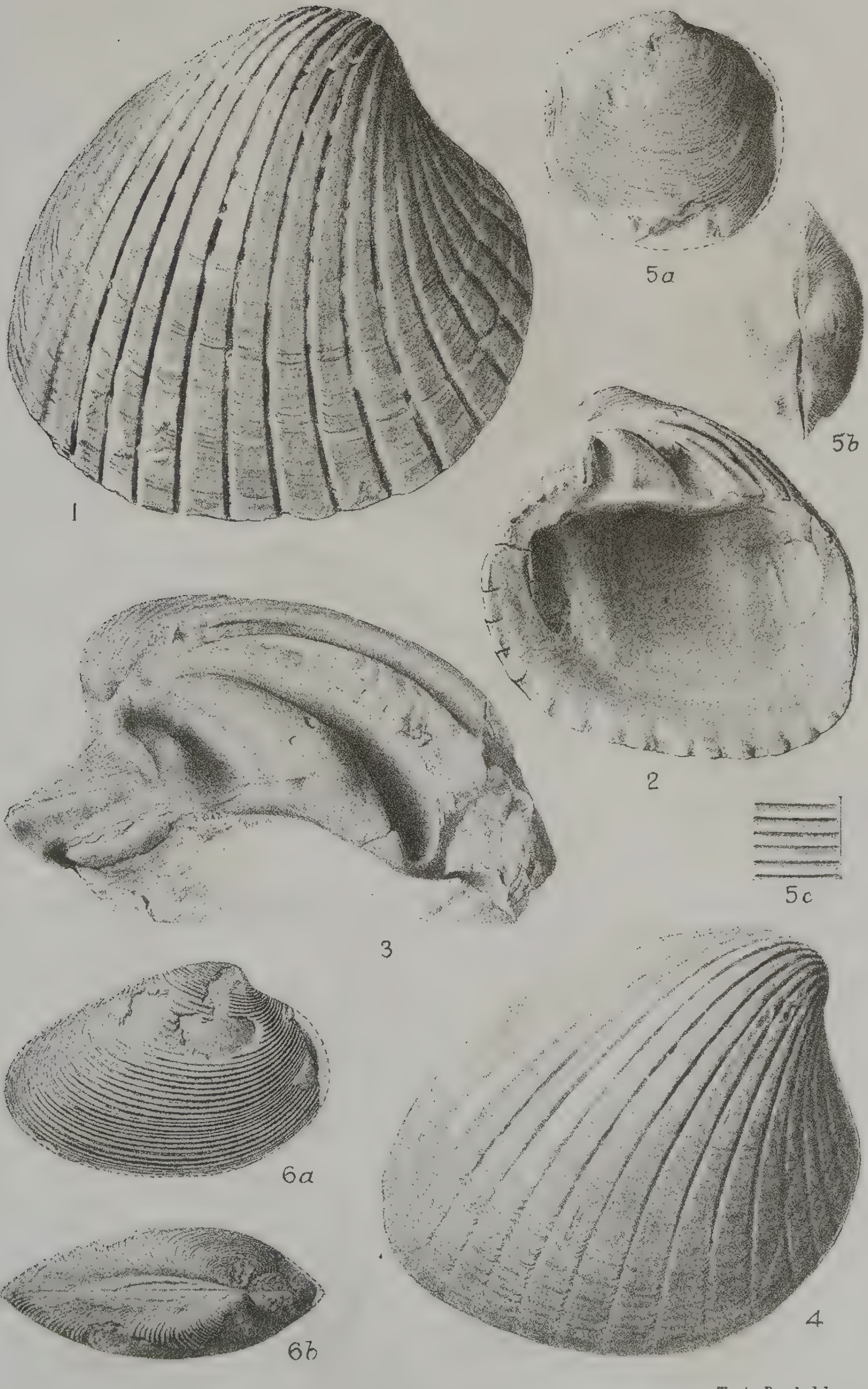

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PLATE V.

Fig. 1.—*Meretrix Bosworthi*, sp. n. Clavilithes Series, near Negritos. *a*, *b*, Right valve; *c*, dorsal view. (P. 72.)

Fig. 2.—*Meretrix negritosensis*, sp. n. Clavilithes Series, near Negritos. Hinge of right valve. (P. 72.)

Fig. 3.—*Cardium*, sp. Turritella Series, near Negritos. Left valve. (P. 73.)

Figs. 4, 5.—*Corbula peruviana*, sp. n. Turritella Series, near Negritos. Fig. 4*a*, Right valve; Fig. 4*b*, left valve; Fig. 4*c*, dorsal view of both valves. Fig. 5, Right valve. All ×1½. (P. 73.)

Fig. 6.—*Corbula Waringi*, sp. n. Turritella Series, near Negritos. *a*, Left valve; *b*, dorsal view of both valves. ×1½. *c*, ornamentation ×12. (P. 74.)

Figs. 7, 8.—*Corbula Arnoldi*, sp. n. Turritella Series, near Negritos. Figs. 7, 8*a*, Left valves; Fig. 8*b*, dorsal view of both valves. All ×1½. (P. 74.)

PLATE V.

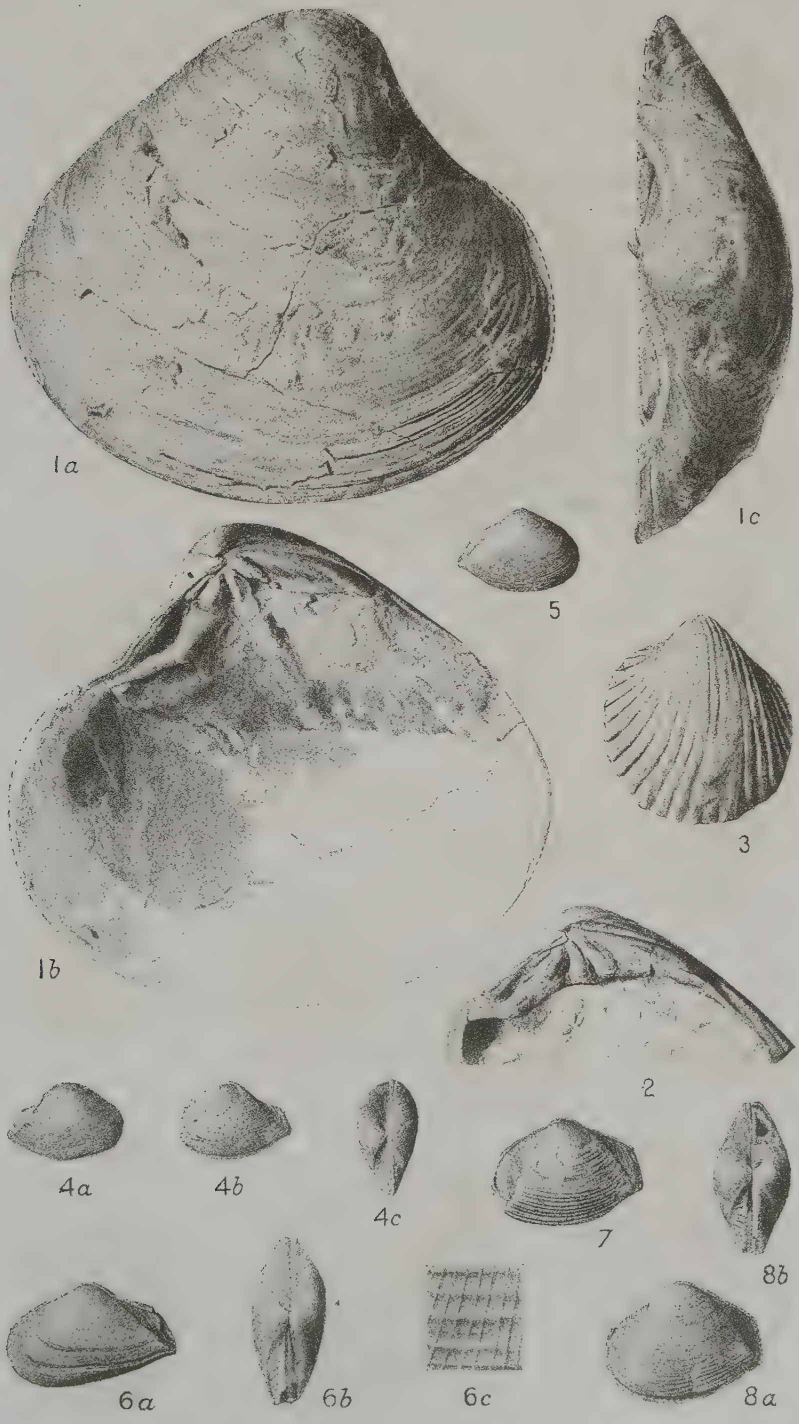

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PLATE VI.

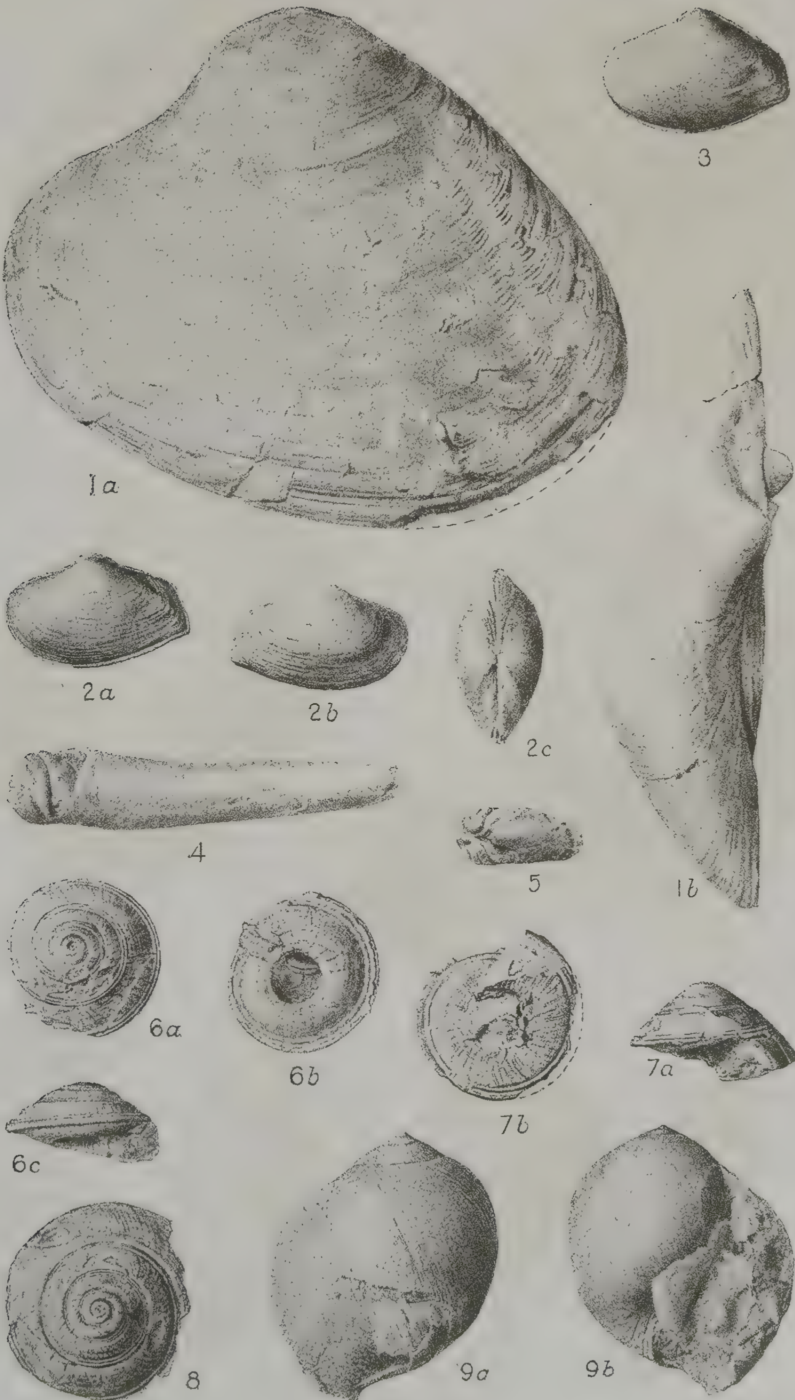
Fig. 1.—*Meretrix negritosensis*, sp. n. Clavilithes Series, near Negritos. Left valve. (P. 72.)

Figs. 2, 3.—*Corbula parinasensis*, sp. n. Parinas Sandstone, near Negritos. Fig. 2*a*, Left valve ; Fig. 2*b*, right valve ; Fig. 2*c*, dorsal view of both valves. Fig. 3, Left valve. All × 1½. (P. 75.)

Figs. 4, 5.—*Teredina*, sp. Turritella Series, near Negritos. Fig. 5, Dorsal view. (P. 75.)

Figs. 6-8.—*Solarium Nelsoni*, sp. n. Fig. 6, Turritella Series, × 1½. Figs. 7, 8, Clavilithes Series. 7 × 1 ; 8 × 1½. All from near Negritos. (P. 76.)

Fig. 9.—*Natica* (*Naticina*), sp. Lower part of Lobitos Formation, N.E. of Negritos. (P. 77.)



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EOCENE MOLLUSCA.

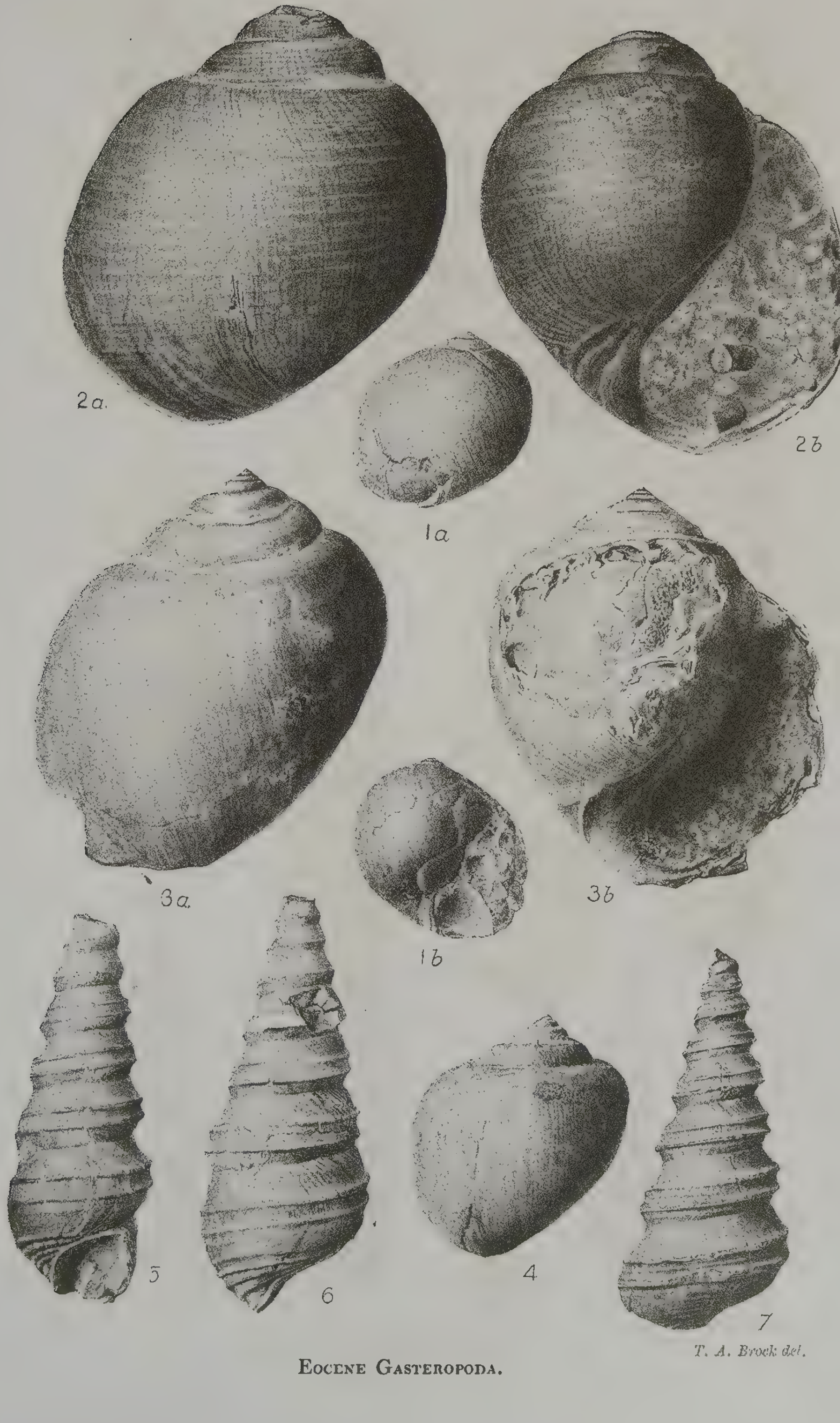
PLATE VII.

Fig. 1.—*Natica* (*Naticina*), sp. Lower part of Lobitos Formation, N.E. of Negritos. (P. 77.)

Fig. 2.—*Ampullina Gabbi*, sp. n. Negritos Formation, Cabo Blanco. (P. 77.)

Figs. 3, 4.—*Ampullina paytensis*, sp. n. Lobitos Formation, Payta. (P. 77.)

Figs. 5-7.—*Turritella negritosensis*, sp. n. Turritella Series, near Negritos. (P. 78.)



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EOCENE GASTEROPODA.

PLATE VIII.

Figs. 1-3.—*Turritella negritosensis*, sp. n. Turritella Series, near Negritos. (P. 78.)

Figs. 4, 5.—*Turritella Lissoni*, sp. n. Turritella Series, near Negritos. (P. 79.)

Figs. 6, 7.—*Turritella Dickersoni*, sp. n. Turritella Series, near Negritos (P. 79.)

Figs. 8-10.—*Turritella Bosworthi*, sp. n. Clavilithes Series, near Negritos. (P. 80.)

Fig. 11.—*Turritella Douvillei*, sp. n. Turritella Series, near Negritos. (P. 80.)

Figs. 12, 13.—*Turritella anceps*, sp. n. Clavilithes Series, near Negritos. (P. 81.)

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Eocene Gasteropoda.

PLATE IX.

Figs. 1, 2.—*Turritella anceps*, sp. n. Clavilithes Series, near Negritos. (P. 81.)

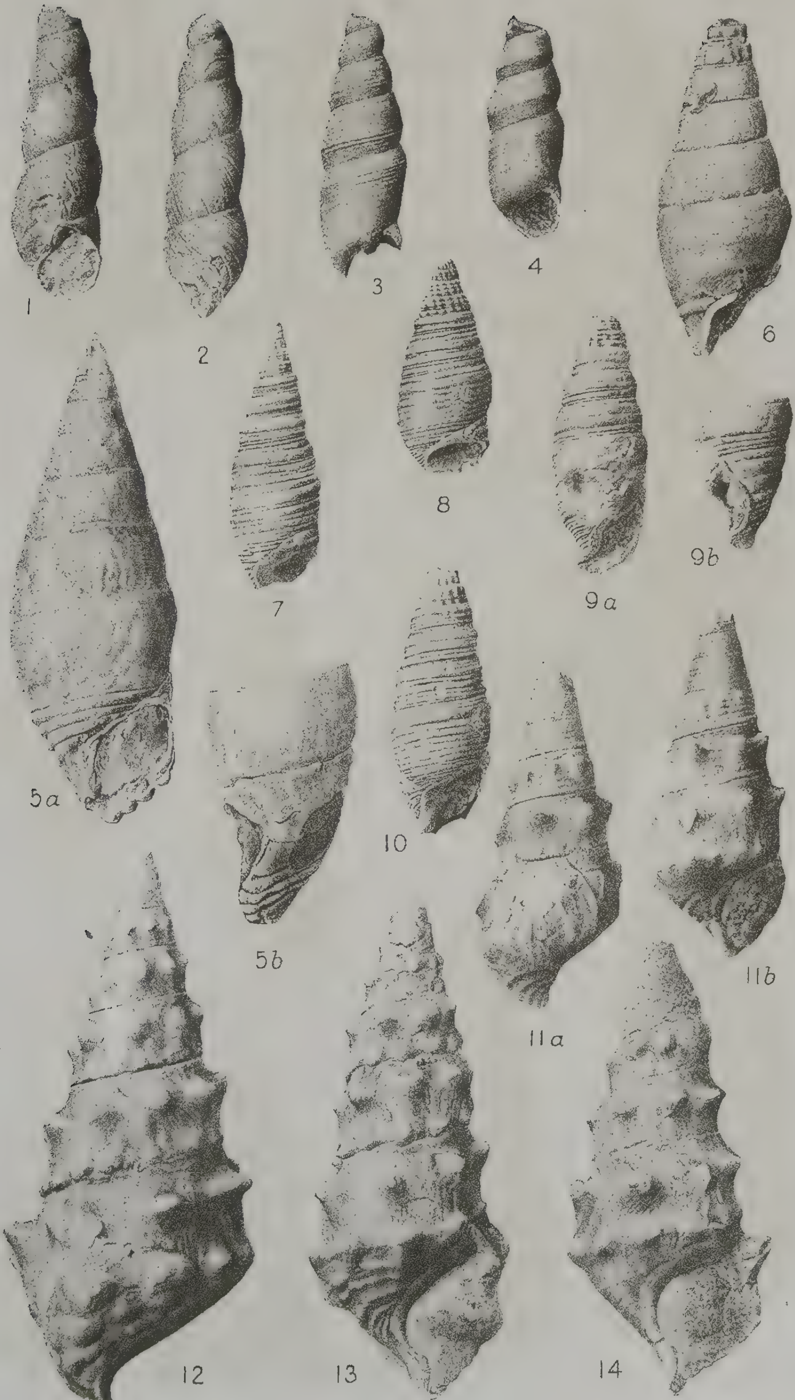
Figs. 3, 4.—*Turritella annectens*, sp. n. Fig. 3, Passage beds to Parinas Sandstone, near Negritos, ×1½. Fig. 4, Parinas Sandstone, near Negritos. (P. 81.)

Figs. 5, 6.—*Morgania magna*, sp. n. Parinas Sandstone, near Negritos. (P. 82.)

Figs. 7-10.—*Morgania costata*, sp. n. Clavilithes Series, near Negritos. All ×1½. (P. 83.)

Fig. 11.—*Melanatria dimorphica*, sp. n. Turritella Series, near Negritos. (P. 83.)

Figs. 12-14.—*Melanatria acanthica*, sp. n. Clavilithes Series, near Negritos. (P. 84.)



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EOCENE GASTEROPODA.

PLATE X.

Fig. 1.—*Melanatria propinqua*, sp. n. Turritella Series, near Negritos. (P. 85.)

Fig. 2.—*Melanatria venusta*, sp. n. Clavilithes Series, near Negritos. (P. 85.)

Fig. 3.—*Pseudoglauconia Lissoni*, Douv. Turritella Series, near Negritos. (P. 85.)

Figs. 4-6.—*Faunus? lagunitensis*, sp. n. Lobitos Formation, 2½ miles E.S.E. of Punta Parinas, Lagunitas. (P. 86.)

Figs. 7-9.—"*Cerithium*" *paytense*, sp. n. Lobitos Formation. Figs. 7, 8, Payta. Fig. 9, Lagunitas. Fig. 8, apical part, ×1½. (P. 87.)

PLATE X.

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PLATE XI.

Figs. 1, 2.—"*Cerithium*" *negritosense*, sp. n. Clavilithes Series, near Negritos. (P. 87.)

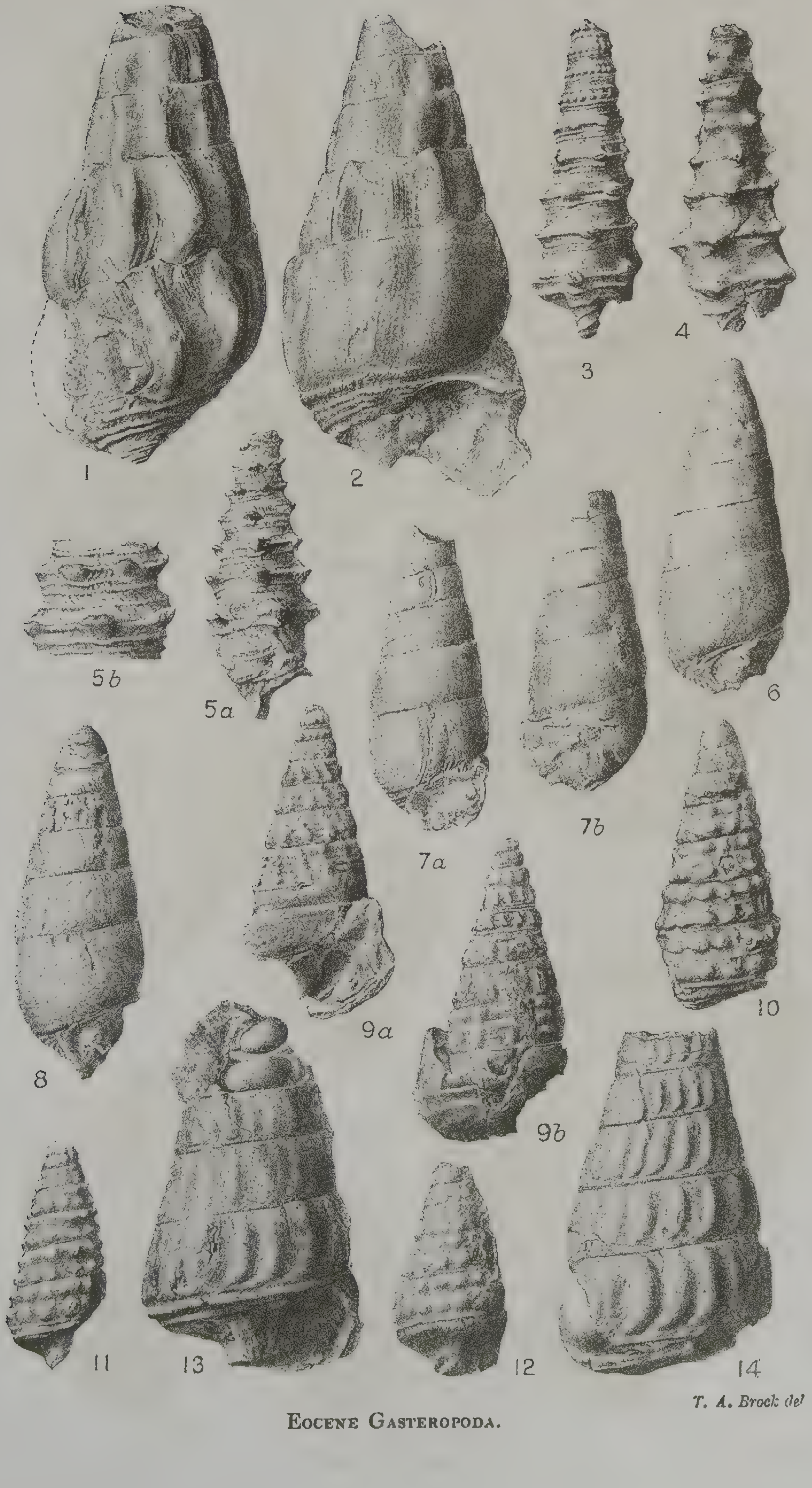
Figs. 3-5.—"*Cerithium*" *Chalwini*, sp. n. Turritella Series, near Negritos. Fig. 3, $\times 1\frac{1}{2}$. Fig. 5*b*, part of 5*a* $\times 2$. (P. 88.)

Figs. 6-8.—*Bezanconia pupoidea*, sp. n. Turritella Series, near Negritos. (P. 89.)

Fig. 9.—*Potamides occidentalis*, sp. n. Clavilithes Series, near Negritos. (P. 90.)

Figs. 10-12.—*Tympanotonus lagunitensis*, sp. n. Lobitos Formation, Lagunitas. (P. 90.)

Figs. 13, 14.—*Telescopium peruvianum*, sp. n. Lobitos Formation, Lagunitas. (P. 91.)



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EOCENE GASTEROPODA.

PLATE XII.

Figs. 1, 2.—*Diastoma americanum*, sp. n. Clavilithes Series, near Negritos. Fig. 2 is compressed so that the apical angle appears too large. (P. 92.)

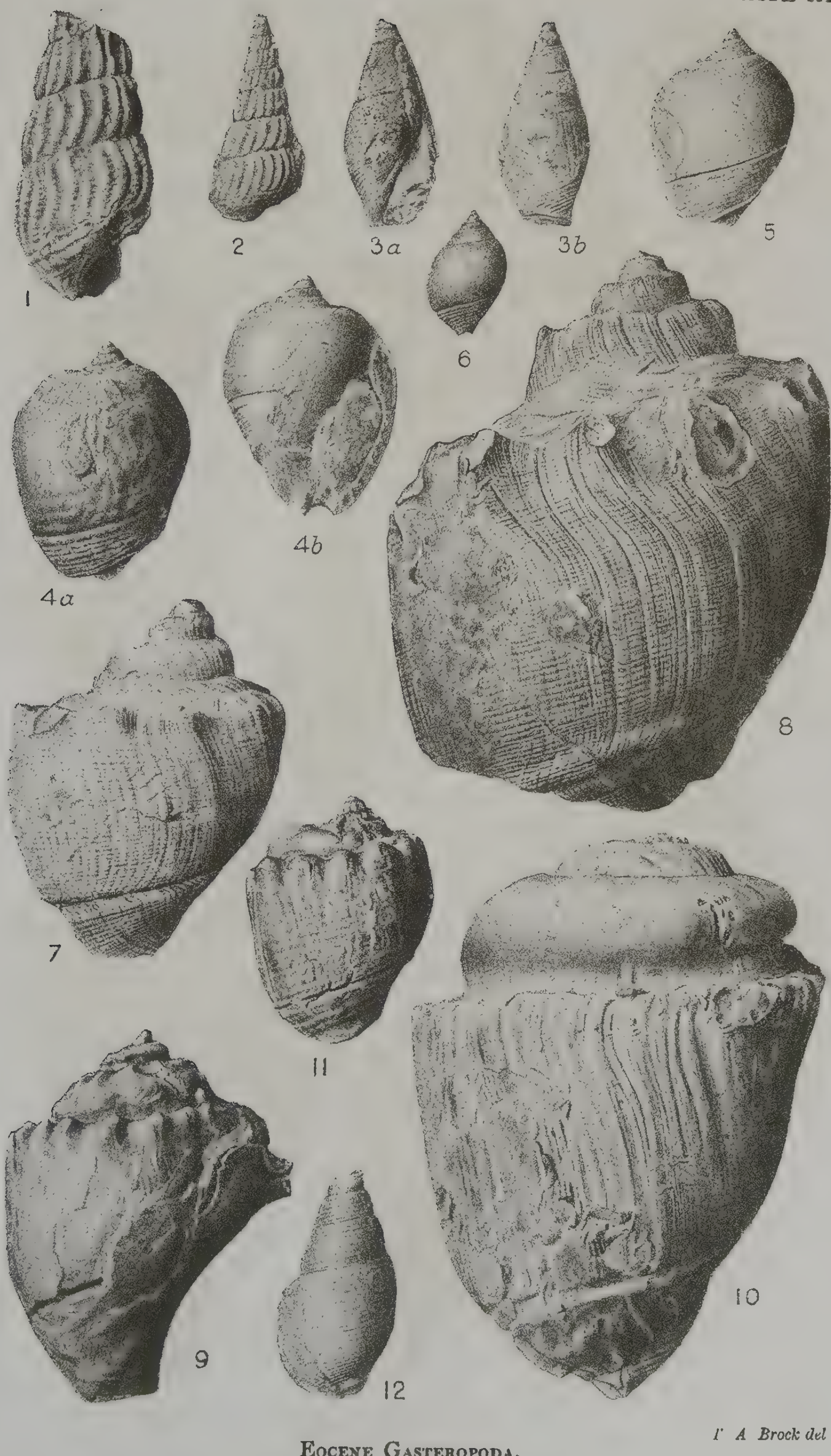
Fig. 3.—*Dientomochilus* (*Ectinochilus*), sp. cf. *laqueata* (Conrad). Lobitos Formation, 10 miles W.N.W. of Sullana. (P. 92.)

Figs. 4-6.—*Pseudoliva parinasensis*, sp. n. Figs. 4, 5, Parinas Sandstone, near Negritos. Fig. 6, Clavilithes Series, near Negritos. (P. 93.)

Figs. 7-11.—*Pseudoliva mutabilis*, sp. n. Figs. 7, 8, Turritella Series. Fig. 9, Clavilithes Series. Figs. 10, 11, Parinas Sandstone. All from near Negritos. (P. 94.)

Fig. 12.—*Nassa lagunitensis*, sp. n. Lobitos Formation, Laginitas. (P. 95.)

PLATE XII.



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EOCENE GASTEROPODA.

PLATE XIII.

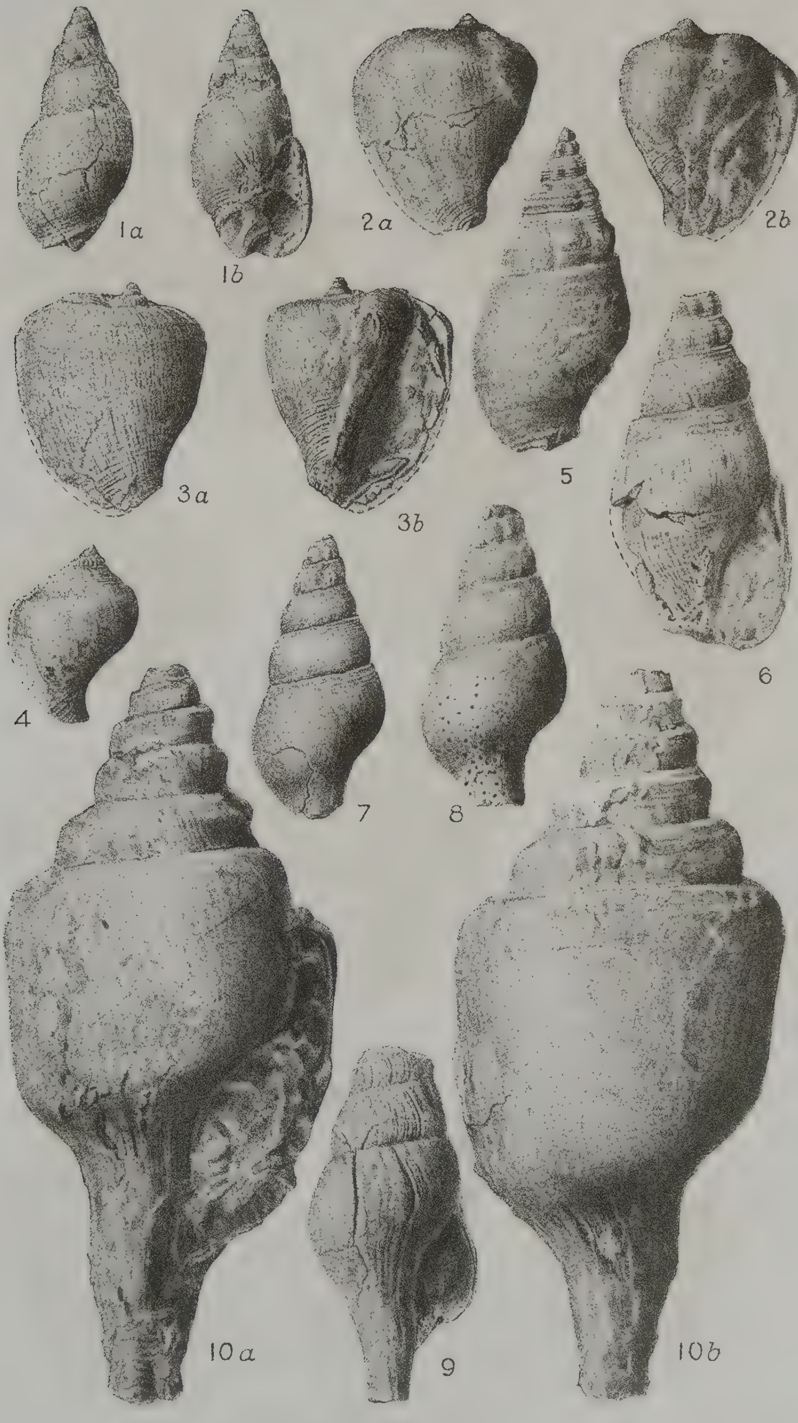
Fig. 1.—*Nassa lagunitensis*, sp. n. Lobitos Formation, Lagunitas. (P. 95.)

Figs. 2-4.—*Strepsidura pacifica*, sp. n. Clavilithes Series, near Negritos. Fig. 4 ×1½. (P. 96.)

Figs. 5, 6.—*Clavilithes Harrisi*, sp. n. Clavilithes Series, near Negritos. (P. 97.)

Figs. 7-9.—*Clavilithes peruvianus*, sp. n. Figs. 7, 9, Clavilithes Series. Fig. 8, Parinas Sandstone. Near Negritos. (P. 98.)

Fig. 10.—*Clavilithes pacificus*, sp. n. Parinas Sandstone, near Negritos. (P. 99.)



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EOCENE GASTEROPODA.

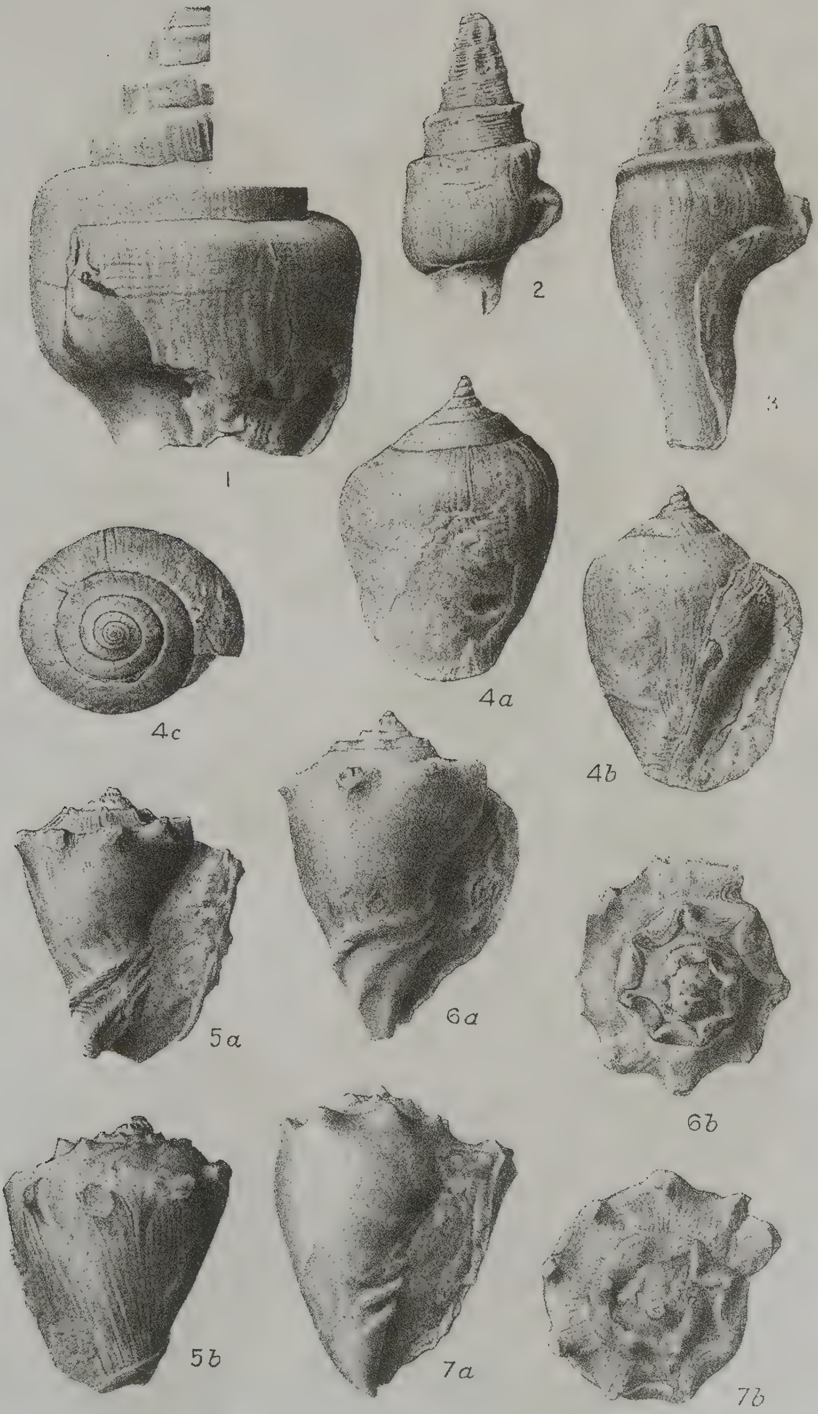
PLATE XIV.

Figs. 1, 2.—*Clavilithes pacificus*, sp. n. Parinas Sandstone, near Negritos. Fig. 2 × 1¼. (P. 99.)

Fig. 3.—*Clavilithes incertus*, sp. n. Parinas Sandstone, near Negritos. (P. 100.)

Fig. 4.—*Sycum americanum*, sp. n. Parinas Sandstone, near Negritos. (P. 101.)

Figs. 5-7.—*Volutospina peruviana*, sp. n. Figs. 5, 6, Turritella Series. Fig. 7, Clavilithes Series. Near Negritos. (P. 101.)



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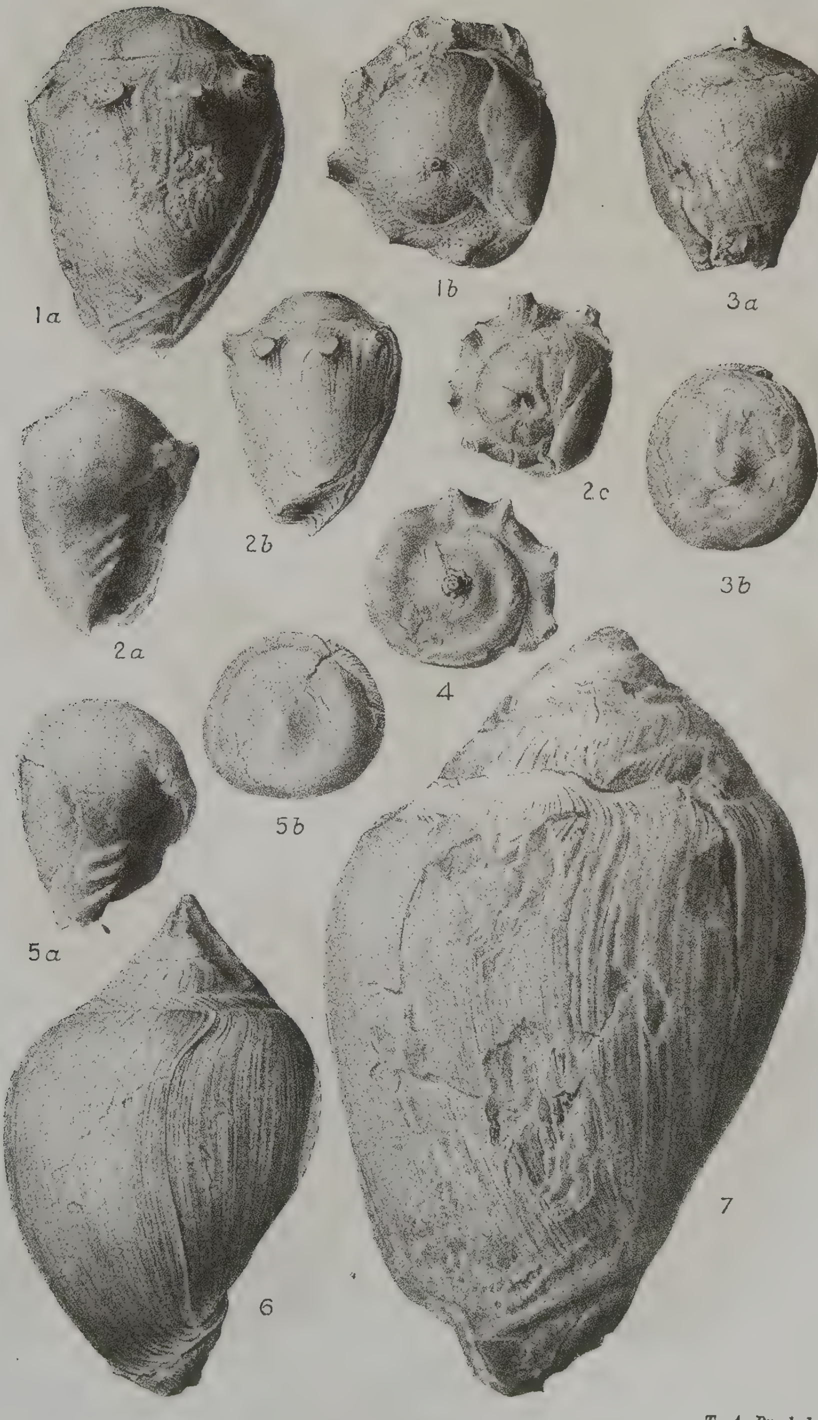
Eocene Gasteropoda.

PLATE XV.

Figs. 1-5.—*Volutospina peruviana*, sp. n. Figs. 1, 2, Clavilithes Series. Figs. 3-5, Parinas Sandstone. Near Negritos. (P. 101.)

Figs. 6, 7.—*Volutospina crassiuscula*, sp. n. Turritella Series, near Negritos. (P. 104.)



EOCENE GASTEROPODA.

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PLATE XVI.

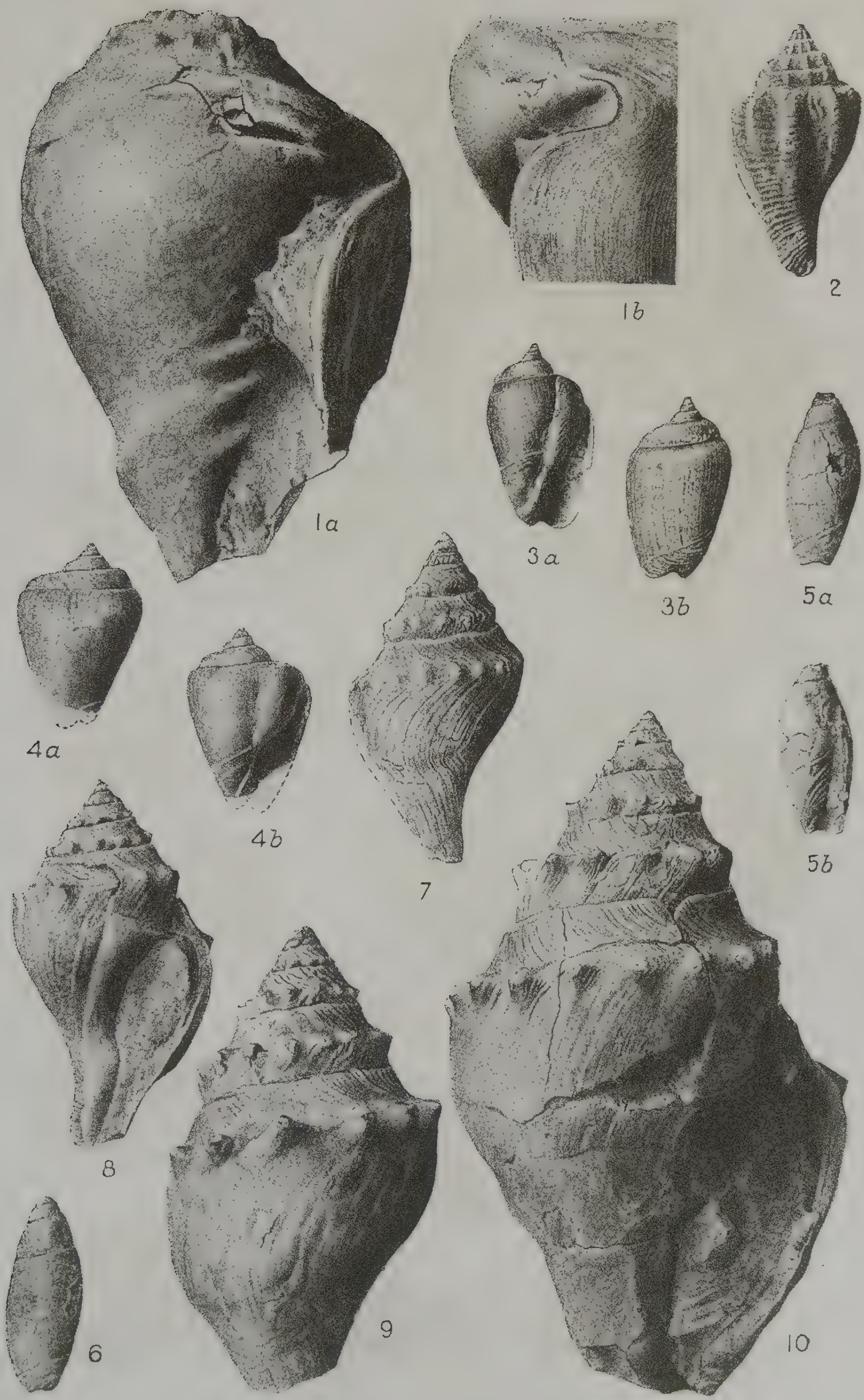
Fig. 1.—*Volutospina crassiuscula*, sp. n. Turritella Series, near Negritos. (P. 104.)

Fig. 2.—*Volutospina meridionalis*, sp. n. Turritella Series, near Negritos. (P. 105.)

Figs. 3, 4.—*Olivancillaria eocenica*, sp. n. Fig. 3, Passage beds to Parinas Sandstone. Fig. 4, Turritella Series. Near Negritos. (P. 105.)

Figs. 5, 6.—*Olivancillaria* (*Agaronia*) *peruviana*, sp. n. Lobitos Formation, Lagunitas. Fig. 5 × 1½. (P. 106.)

Figs. 7-10.—*Surcula occidentalis*, sp. n. Clavilithes Series, near Negritos. (P. 106.)



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EOCENE GASTEROPODA.

PLATE XVII.

Figs. 1, 2.—*Surcula Thompsoni*, sp. n. Clavilithes Series, near Negritos. (P. 107.)

Fig. 3.—*Surcula Thompsoni*, var. Turritella Series, near Negritos. (P. 108.)

Fig. 4.—*Callianassa parinasensis*, sp. n. Bottom of Lobitos Formation, Punta Parinas. Left cheliped. (P. 114.)

Figs. 5, 6.—*Callianassa americana*, sp. n. Clavilithes Series, near Negritos. (P. 115.)

Figs. 7-10.—*Xanthopsis errans*, sp. n. Clavilithes Series, 1 mile E. of Negritos. Figs. 8, 9, Chelæ; Fig. 8*b*, upper margin of Fig. 8*a*. Fig. 10*a*, *b*, Dactylos. (P. 115.)

Fig. 11.—*Thaumastoplax coccnica*, sp. n. Clavilithes Series, 1 mile E. of Negritos. Fig. 11*b*, Anterior view of 11*a*. × 1½. (P. 117.)

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Eocene Gasteropoda and Crustacea.

PLATE XVIII.

Fig. 1.—*Solarium sexlineare*, Nelson. Zorritos Formation, Quebrada Charan. (P. 109.)

Figs. 2, 3.—*Turritella infracarinata*, Grzybowski. Zorritos Formation. Fig. 2, Zorritos. Fig. 3, Quebrada Charan. (P. 109.)

Fig. 4.—*Turritella robusta*, Grzybowski. Zorritos Formation, Zorritos. (P. 110.)

Fig. 5.—*Scapharca zorritosensis*, sp. n. Zorritos Formation, Zorritos. Fig. 5*a*, Right valve; Fig. 5*b*, dorsal view of Fig. 5*a*; Fig. 5*c*, hinge and area of Fig. 5*a*. (P. 112.)

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MIOCENE MOLLUSCA.

PLATE XIX.

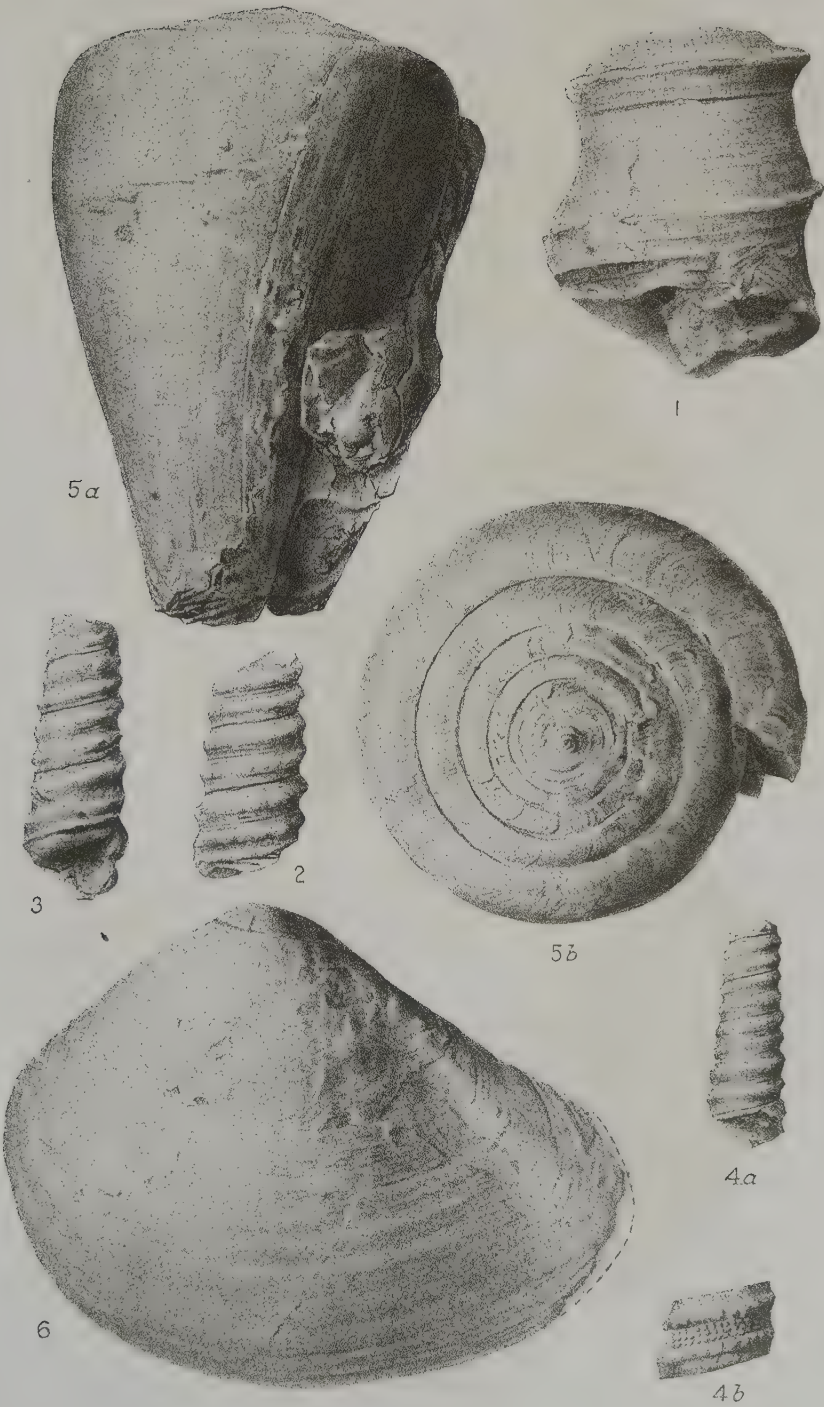
Fig. 1.—*Turritella robusta*, Grzybowski. Zorritos Formation, Zorritos. (P. 110.)

Figs. 2-4.—*Turritella*, sp. cf. *altilira*, Conrad. Zorritos Formation, Quebrada Charan. Fig. 4*b*, part of Fig. 4*a* ×2. (P. 110.)

Fig. 5.—*Conus*, sp. Zorritos Formation, Quebrada Charan. (P 111.)

Fig. 6.—*Crassatellites charanensis*, sp. n. Zorritos Formation, Quebrada Charan. Left valve. (P. 112.)

PLATE XIX.



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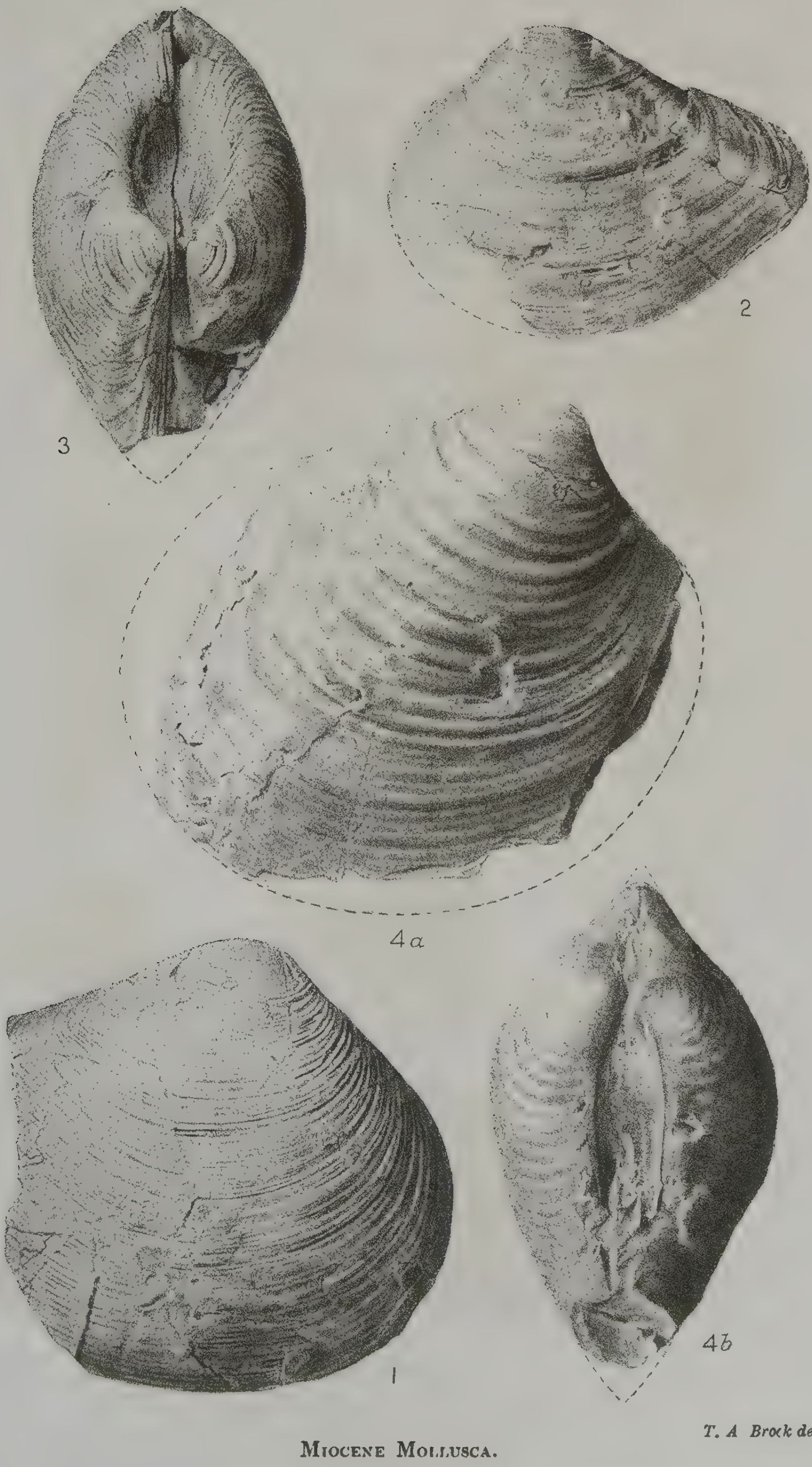
MIOCENE MOLLUSCA.

PLATE XX.

Figs. 1-3.—*Crassatellites charanensis*, sp. n. Zorritos Formation, Quebrada Charan. Fig. 1, Right valve. Fig. 2, Left valve. Fig. 3, Dorsal view of both valves. (P. 112.)

Fig. 4.—*Clementia* sp., cf. *dariena* (Conrad). Zorritos Formation, Quebrada Charan. Fig. 4*a*, Right valve; Fig. 4*b*, dorsal view of Fig. 4*a*. (P. 113.)



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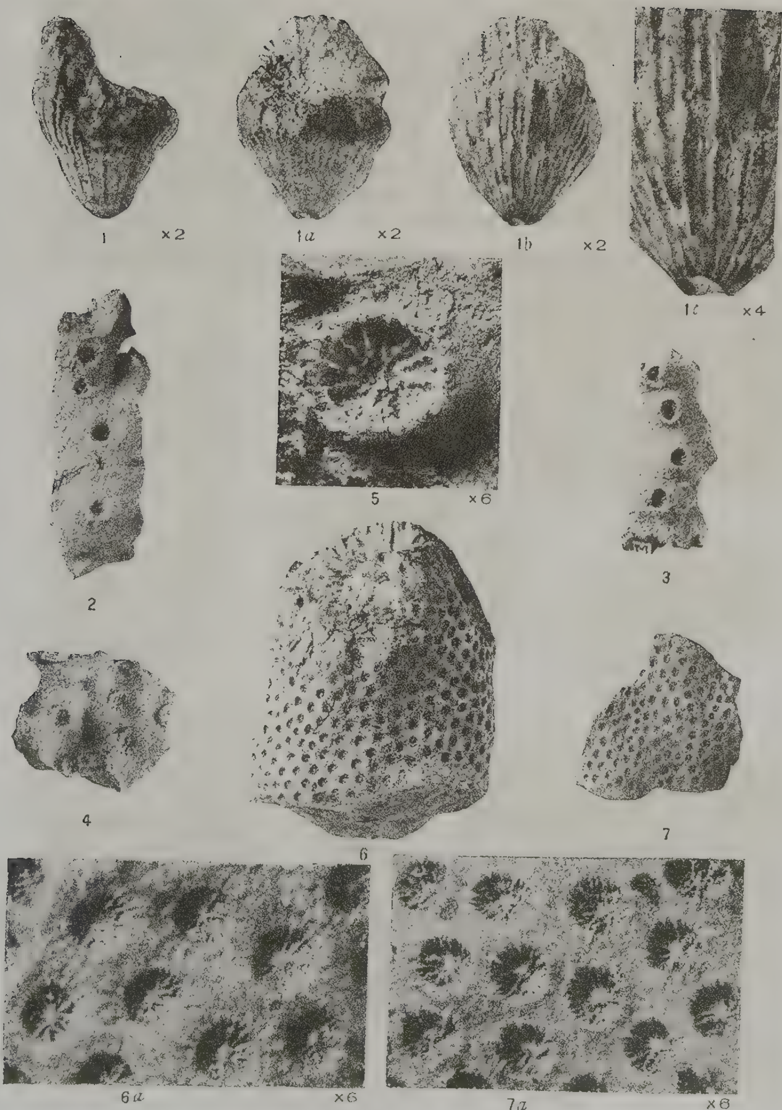
MIOCENE MOLLUSCA.

PLATE XXI.

Figs. 1, 1*a*, 1*b*, 1*c*.—*Paracyathus peruvianus*, Vaughan, sp. n. Clavilithes Series, near Negritos. Four views of the holotype. Fig. 1, Side view of corallum, ×2; Fig. 1*a*, Front of corallum, ×2; Fig. 1*b*, Back of corallum, ×2; Fig. 1*c*, Costæ on back of corallum, ×4. (P. 126.)

Figs. 2, 3, 4, 5.—*Oculina peruviana*, Vaughan, sp. n. Clavilithes Series, near Negritos. One view of each of the four cotypes. Figs. 2, 3, 4, General views, each natural size. Fig. 5, Calice, ×6. (P. 127.)

Figs. 6, 6*a*, 7, 7*a*.—*Peruviastrea peruviana*, Vaughan, gen. n. and sp. n. Clavilithes Series, near Negritos. Two views of each of the two cotypes. Fig. 6, General view, natural size; Fig. 6*a*, Calices, ×6, of the larger cotype. Fig. 7, General view, natural size; Fig. 7*a*, Calices, ×6, of the smaller cotype. (P. 129.)



EOCENE CORALS.

PLATE XXII.

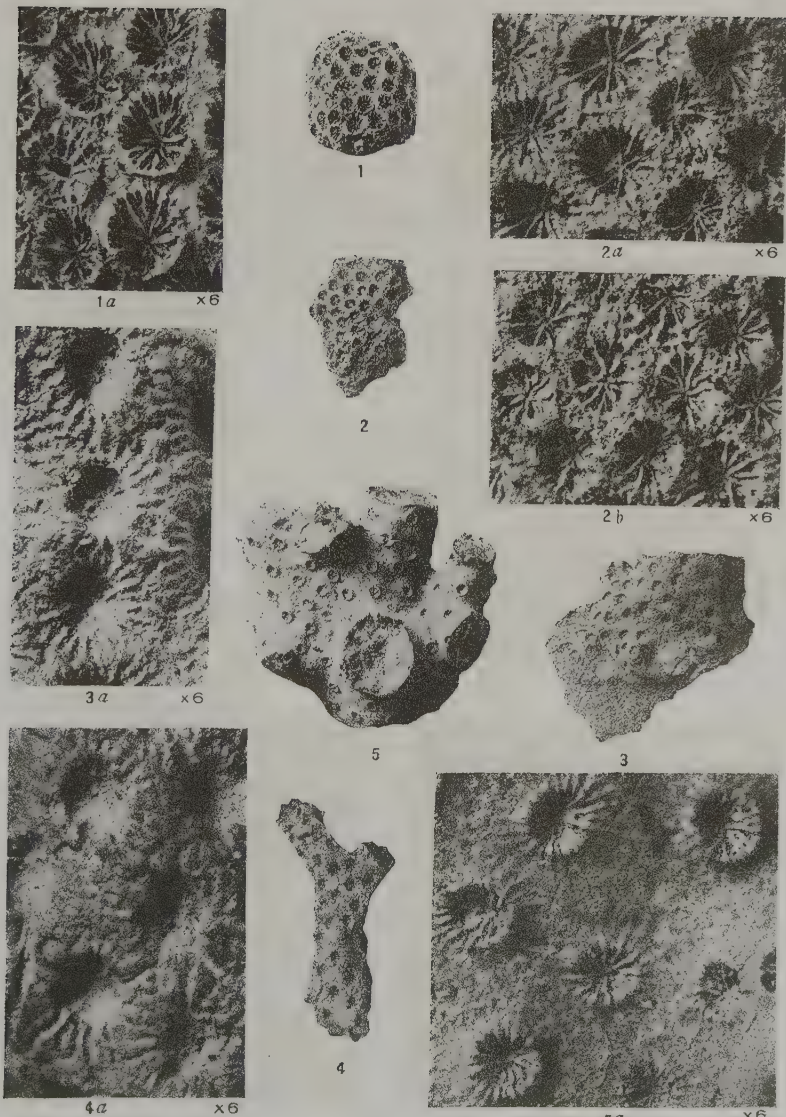
Figs. 1, 1*a*.—*Haimesiastræa conferta*, Vaughan. Two views of a branch terminal from the lower Eocene Tuscahoma Formation of the Wilcox Group at Greggs Landing, Alabama, for comparison with the views of *Haimesiastræa peruviana*. Fig. 1, General view, natural size ; Fig. 1*a*, Calices, ×6. (P. 131.)

Figs. 2, 2*a*, 2*b*.—*Haimesiastræa peruviana*, Vaughan, sp. n. Turritella Series, near Negritos. Three views of the holotype. Fig. 2, General view, natural size ; Figs. 2*a*, 2*b*, Calices, ×6, of each side. (P. 130.)

Figs. 3, 3*a*, 4, 4*a*.—*Haimesiastræa humilis*, Vaughan, sp. n. Turritella Series, near Negritos. Views of the holotype and the paratype. Fig. 3, General view, natural size ; Fig. 3*a*, Calices, ×6, of the holotype. Fig. 4, General view, natural size ; Fig. 4*a*, Calices, ×6, of the paratype. (P. 131.)

Figs. 5, 5*a*.—*Haimesiastræa distans*, Vaughan, sp. n. Clavilithes Series, near Negritos. Two views of the holotype. Fig. 5, General view, natural size ; Fig. 5*a*, Calices, ×6. (P. 132.)

PLATE XXII.

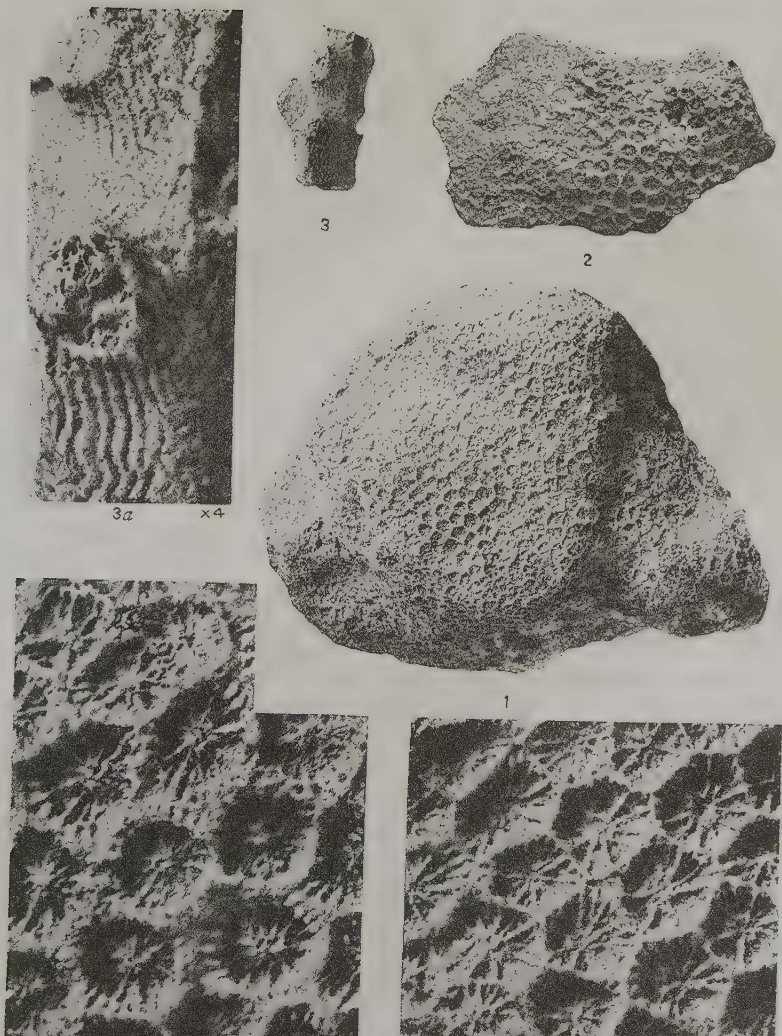


EOCENE CORALS.

PLATE XXIII.

Figs. 1, 1*a*, 2, 2*a*.—*Stephanocœnia peruviana*, Vaughan, sp. n. Clavilithes Series, near Negritos. Views of the holotype and the paratype. Fig. 1, General view, natural size; Fig. 1*a*, Calices, ×6, of the holotype. Fig. 2, General view, natural size; Fig. 2*a*, Calices, ×6, of the paratype. (P. 133.)

Figs. 3, 3*a*.—*Dendrophyllia peruviana*, Vaughan, sp. n. Clavilithes Series, near Negritos. Two views of the holotype. Fig. 3, General view, natural size; Fig. 3*a*, Part of surface, to show the costæ, ×4. (P. 134.)



Eocene Corals.

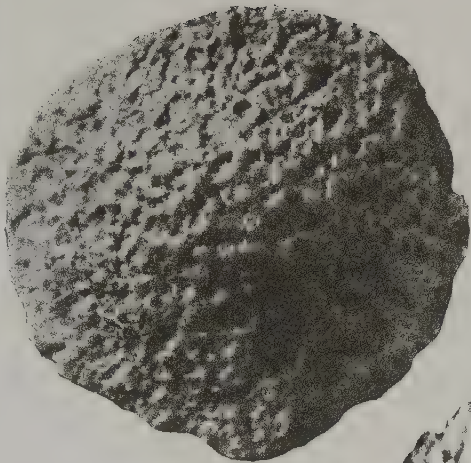
PLATE XXIV.

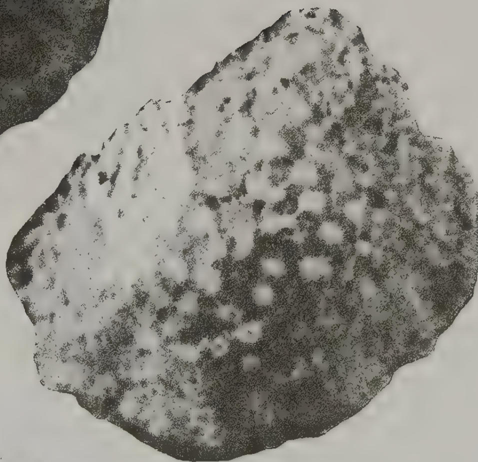
Fig. 1.—*Lepidocyclina (Nephrolepidina) peruviana*, Cushman, sp. n., ×15. Lobitos Formation, Lagunitas. (P. 138.)

Fig. 2.—*Lepidocyclina antillea*, Cushman, ×15. Lobitos Formation, Mount Organo. (P. 137.)

Fig. 3.—*Orthophragmina peruviana*, Cushman, sp. n., ×15. Lobitos Formation, near Negritos. (P. 138.)

Figures from photographs of original specimens.





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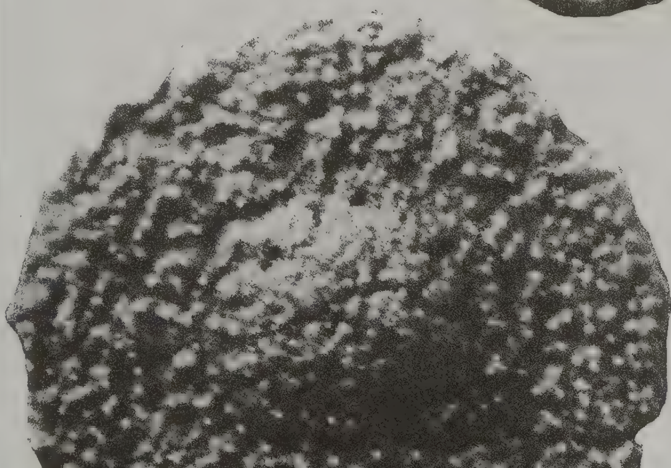


3

FORAMINIFERA.

PART III

GEOLOGY OF THE QUATERNARY PERIOD, ON A PART OF THE PACIFIC COAST OF PERU

By T. O. Bosworth, D.Sc., M.A.

SECTION A:

INTRODUCTION, AND OUTLINE OF THE PRE-QUATERNARY GEOLOGY

CHAPTER I

INTRODUCTION

THERE is on the west coast of South America, a long strip of territory characterised by a remarkable series of deposits which is still in course of accumulation.

Marine erosion and transgression, the birth of a marine formation, and the process of its emergence from the sea, are here displayed with clearness that is perhaps unique.

As explained in the introduction to Part I., the author has spent several years during the period 1912-1918, making investigations in this region.

Geological literature [1] contains very little information about this territory; and in conducting these

[1] There is, however, a paper by J. Grzybowski, published in 1899 (*Neues Jahrb. f. Min.* etc., Beil-Band xii. p. 610); also there are occasional notes in the *Boletin del Cuerpo de Ingenieros del Peru.*

Some information applicable to this area is contained in *The Andes of Southern Peru*, by Isaiah Bowman, 1916, published since the present paper was composed.

See also "The Physiography of the Southern Andes," by V. F. Marsters, *Annals of New York Acad. of Sciences*, 1912, vol. xxii.

surveys the country was dealt with as though it were unexplored.

During the year 1913, the author was assisted by Mr. H. G. Busk, B.A. For several months of 1914, Mr. A. J. Romanes, M.A., also was in the field in connection with the same survey. In the northern part of the area geological work by Mr. Barrington Brown, M.A., was in progress for several years, and some of his collections and findings also were discussed. A preliminary investigation of one part of the area was made in 1909 by Mr. Beeby Thompson, whose observations were duly described to the Geological Society.

Part III. of this volume is concerned with the earth-movements and with the Quaternary marine erosion and deposition. The Tertiary rocks are dealt with in Part I.

CHAPTER II

GENERAL GEOGRAPHY OF THE REGION

THE country to be considered is a part of the "Littoral" of Peru, lying between latitude 4° 5′ south and 5° 6′ south. In other words, it is a narrow strip of country contained between the Cordilleras and the ocean, commencing at the village of Mancora in the north and extending for 100 miles along the coast as far south as the Port of Payta. (See map, Folder No. I., in Part I.)

This territory is almost wholly desert (Desierto de Tumbes), but the southern part of it is traversed by the Rio Chira, bearing water from the distant mountains.

The country is almost uninhabited except for villages along the river, and a few mining settlements along the coast, where water is obtained by evaporation from the sea.

A range of desert mountains known as the Cerros de Amotape, which is the outermost of the Cordilleras, borders the Littoral on the east side. This range has a general north-east direction. To northward it joins on to other mountain masses, but to the south it terminates 12 miles north of the Rio Chira. Opposite to Punta Parinas, the most western point of South

America, the mountains are within 16 miles of the sea. They rise abruptly from the desert plain to altitudes of 3000-5000 feet.

The country between the mountains and the sea (the Littoral) is in parts flat though deeply trenched; and in other parts it is much dissected and very rugged, though the elevation is usually considerably below 1000 feet.

Large areas are occupied by tablelands known locally as "Tablazos," which in some places extend from the present sea-cliffs right to the foot of the Amotape Mountains. This peculiarity of the topography is conspicuous when viewed from the sea, and must have been remarked by many a voyager travelling along the west coast.

The character of the Tablazos will be described below, and an endeavour will be made to explain the remarkable chain of events which make up the recent history of this piece of the earth's crust.

Indices of Locality used in these Pages.

On the accompanying maps, lines of latitude and longitude have been drawn at 10-mile intervals, for purpose of reference. The initial point from which they are numbered is Punta Parinas, the most western cape of South America. The latitude and longitude are expressed in miles.

From north to south, the principal places which will be mentioned are :

Mancora	A small village (lat. 40, long. 22).
Cabo Blanco	A headland at which the general direction of the coast-line changes (lat. 29, long. 6).
Lobitos	An oil-mining settlement on the coast (lat 16, long. 4).
Quebrada Parinas	An important dry valley (lat. 10).
Talara	A port of the petroleum industry (lat. 7, long. 3).
La Brea	A landmark 12 miles inland (lat. 1, long. 13).
Negritos	An oil-mining settlement on the coast (lat. 1, long. 2).
Punta Parinas	The most western point of South America (lat. 0, long. 0).
Rio Chira	A river, with villages along it (lat. –16).
Amotape	An old village on the River Chira (lat. –15, long. 21).
Payta	A seaport (lat. –13, long. 14).
Cerros de Payta	Small mountains south of Payta (lat. –20).

CHAPTER III

ABRIDGED TABLE OF FORMATIONS

III. Quaternary.

Raised sea-floors, forming Tablazos (tablelands) which extend inland 10-20 miles. They consist of shell-limestones, calcareous sandstones, and pebble beds, with beaches at their inland margins.

A breccia-fan from the mountains, 100 feet thick, is spread over a large part of the Tablazos.

Extensive river terraces, corresponding with the uplifts, occur in the valleys which are cut in the Tablazos.

The principal Tablazos are :

Lobitos Tablazo	altitude,	50-110 feet
	thickness,	5-15 ,,
Talara Tablazo	altitude,	150-350 ,,
	thickness,	8-25 ,,
Mancora Tablazo	altitude,	200-1200 ,,
	thickness,	75-250 ,,

II. Tertiary.

Intensely faulted and inclined deposits, aggregating 20,000 feet or more. Mainly clay-shales with sandstones. Underneath the Tablazo deposits they occupy the whole area, extending inland as far as the flank of the Amotape Mountains which was their shore-line, and against which they lie unconformably.

Zorritos Formation	5000 feet
Lobitos Formation	5000 ,,
Negritos Formation	7000 ,,

I. Pre-Tertiary.

Rocks involved in the Amotape Mountain Range, which during the Tertiary Period was much the same as it is to-day.

Mesozoic	Pananga Limestone (Cretaceous). Tablones Group (Jurassic ?).
Palæozoic and Archean	Cerro Prieto Slates and Calcareous Slates, Amotape Slates and Quartzites with intrusive Granite, etc.

CHAPTER IV

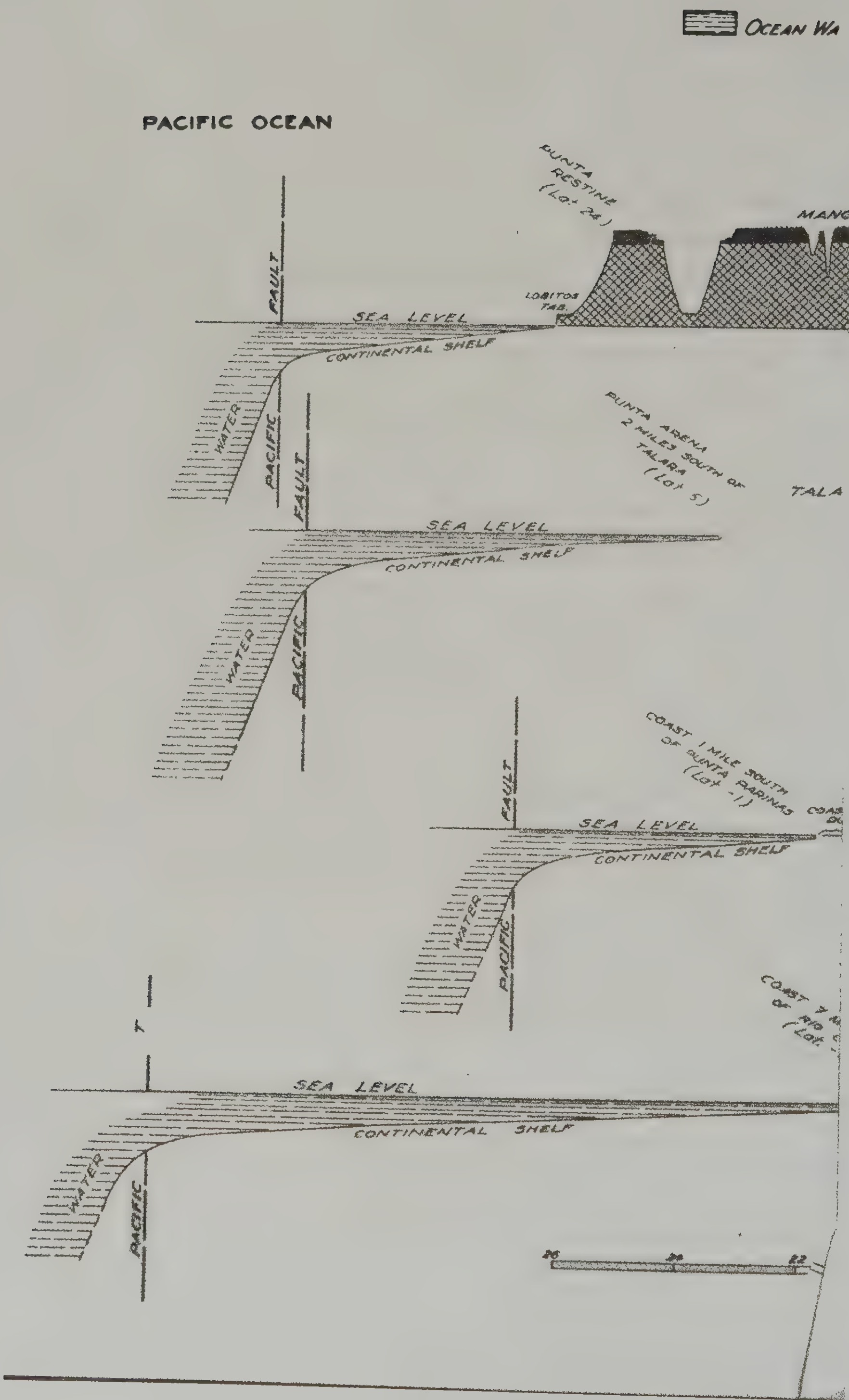
THE TOPOGRAPHY

Standing upon one of the mountain summits and looking out towards the ocean, we see that the country comprises five main topographic elements. (See Folder IV., and sections, Folders V. and VI.)

(*a*) The sharp, steep Amotape Mountains, formed of the old hard and folded rocks, rising abruptly from the desert plain (elevation 500-1000 feet) to heights of 3000-5000 feet. (See Fig. 52.)

(*b*) A great Breccia Cone lying around the foot of the mountains (Fig. 36), and stretching out from them about eight miles towards the sea. This deposit also extends back up all the dry valleys into the mountains. Deep gorges and canyons have been cut into the cone, and in some places it has been intensely dissected (see Fig. 51) or entirely removed; and in such places we notice the Tertiary resting against the hard mountain crags.

(*c*) Farther in the distance, we see the breccia cone fade away and die out upon what seems to be a perfectly level plain, and which also is in parts dissected or trenched


OCEAN WA
PACIFIC OCEAN
PUNTA RESTINE (Lot 24)
MANG
FAULT
LOBITOS TAB.
SEA LEVEL
CONTINENTAL SHELF
WATER
PACIFIC
PUNTA ARENA 2 MILES SOUTH OF TALARA (Lot 5)
TALA
FAULT
SEA LEVEL
CONTINENTAL SHELF
WATER
PACIFIC
COAST 1 MILE SOUTH OF PUNTA PARINAS (Lot -1)
FAULT
SEA LEVEL
CONTINENTAL SHELF
WATER
PACIFIC
SEA LEVEL
CONTINENTAL SHELF
WATER
PACIFIC
26
24
22

with deep canyons. This is the Mancora Tablazo, about 400-600 feet above the sea in the central part of our map.

Yet farther, if the sand-storms are not too thick, we perceive an abrupt edge to this Tablazo, and there is a drop of perhaps 100 feet or more, down to another similar Tablazo at 300 feet above sea-level. In the far distance we see this lower Tablazo, in some directions, stretching right to the ocean, where it terminates in a sea-cliff 280 feet high. (See Figs. 42, 45, 29.)

(*d*) Also in the distance we see large areas of intricate, rough bad-lands, with altitudes somewhat less than the Tablazos. These are areas from which the mantle of Tablazo beds has been denuded away; and the underlying inclined shales and sandstones of the Tertiary have determined the topography. (See Fig. 9.)

(*e*) In the farthest distance, bordering the coast, we may see large flat embayments in the Tablazos, which have been cut by wave and wind and flood. These are wind-swept sandy plains at about sea-level. (See Fig. 49.)

Some of these, known as salinas, are flooded by the sea at spring-tides, which afterwards leaves them covered over with glittering white salt.

CHAPTER V

THE TERTIARY LAND AND ITS COAST

The pre-Tertiary rocks are exposed in the Amotape Mountains; in the Mountains of Payta; and south of this region, in Cerro Yllesca.

The upfolding and building of these mountains was a pre-Eocene event, and since then they have undergone but little deformation.

Approaching the mountains the Tertiary clays and sandstones pass into littoral deposits and beaches, which are well seen resting against the mountain flanks.

Thus during the Tertiary Period these mountains were the western edge of the South American Continent, and the Eocene Pacific Ocean had its shore along the foot of them. The southern end of the Amotape Mountains was a large promontory or peninsula, closely surrounded on the west-south and south-east by the Eocene sea; whilst the mountains of Payta and also Cerro Yllesca apparently were large islands. A rugged coast with many small rocky islands must have been presented to the sea by these mountains, which now rise up very steeply through the comparatively flat Tertiary deposits.

The pre-Tertiary rocks are of some importance in

the following problems because of the material which they supplied to the later accumulations.

In this part of Peru, the outermost range of mountains is composed mainly of slates and quartzites, with granite intrusions.

Thus the southernmost 15 miles of the Amotape Mountains consists chiefly of slates and quartzites without fossils, probably of pre-Cambrian age. These will be referred to as the Amotape Slates and Quartzites. Infolded with them are some slates with bands of impure limestone containing crinoids and brachipods, which probably belong to the Lower Palæozoic.

Into the Amotape Slates a coarse white granite has been intruded, forming Cerro Buenos Aires. It is surrounded by a splendid aureole of contact metamorphism, about a mile wide, comprising zones of mica-schist, andalusite-schist, and spotted slates. (This is described in another paper.)

A little farther north (lat. 13), the mountains consist of Cretaceous and other Mesozoic rocks, which are brought down by a great transverse trough-fault of post-Tertiary age (Pananga Fault). One of the most interesting members is the Pananga Limestone, of which one portion is a hard limestone made up mainly of a large cyprea, or similar shell, two or three inches long, accompanied by some other gasteropods, lamellibranchs, and ammonites.

These Mesozoic rocks continue northward for 7 miles, after which the faulting brings the Amotape Slates and Quartzites up again, and the range resumes its normal aspect.

The isolated group of small mountains near Payta (" Silla de Payta "), at the south-west corner of our

map, and also Cerro Yllesca, a farther 50 miles southward, consist of similar slates, intrusions, and contact-altered rocks.

In the southern part of our area, the mountains are some 50 miles inland—Cerro Ereo (see map, Folder I., in Part I., lat. 8, long. 68), etc.—and lie beyond the limits of the special map (Folder IV.). They include large massifs of dolerite, porphyrite, and other igneous rocks.

CHAPTER VI

THE TERTIARY SUBSIDENCE MOVEMENT

In the preceding paper it was shown that the whole of the present Littoral was covered by Tertiary sediments to a depth of 20,000 feet or more.

The deposit consists of clay-shales and sandstones, and is obviously of shallow-water deposition.

Innumerable seams of beach pebbles are a feature of the deposits. The stones are greatly worn and are of flattened shape. They are composed of quartzite, quartz-schist, andesite, and porphyrite, etc. They are quite different from the pebbles in the ensuing Quaternary deposits, but, like them, they seem not to have been derived from the nearest mountains.

Most of these beaches are crowded with fossil shells, broken bits of coral, and pieces of driftwood riddled with boring molluscs.

Towards the inland margin of the area a coastal facies is developed, including thick sandstone, and basal breccias and thick pebble-beaches resting against the Amotape Slates.

The coastal phase is found in each subdivision of the Tertiary as it approaches the mountains; and plainly the successive deposits overlapped one another, in turn, on to the mountain flanks. The contacts exposed range from the Clavilithes Series of the

Negritos Formation up to the lower part of the Lobitos Formation, the exposed strand-line having an altitude varying from about 700 feet to 1200 feet. Doubtless a larger range would be visible were it not for the Breccia Cone which thickly covers most of the ground along the foot of the mountains.

The mountains rise up abruptly, from the comparatively flat Tertiary beds, as sharp steep crags and peaks of all sizes. They bear all the appearance now of being the crests of a once more lofty range which has been " drowned " in the Tertiary deposits. The main summits now have altitudes of 3000-5000 feet.

Therefore it is concluded—from the shallow-water character and the great thickness of the Tertiary accumulations, and from the rise of their strand-line up the mountain flanks and the partial drowning of the mountains—that a large subsidence was in progress during the Tertiary Period.

The subsiding area included that part of the Eocene continental shelf which is the present Littoral, and also at least the western margin of the mountains.

The movement was probably oscillatory, with the downthrows continually exceeding the uplifts.

The net total of this subsidence possibly was least at the mountains, though not less than several thousand feet. Ten miles from the mountains the subsidence was not less than 10,000 feet.

The western limit of the subsided area is unknown. Forty miles from the mountains, or 25 miles from the present shore, the sea now has a depth of 12,000 feet.

CHAPTER VII

THE POST-TERTIARY GEO-FAULT AND THE BLOCK-FAULTING OF THE LITTORAL

After the deposition of the Tertiary and before the Quaternary beds were laid over them, a long interval of time elapsed during which the fauna of the Tertiary became extinct.

During this interval the Tertiary deposits underwent great disturbance by earth movements, and they also suffered extensive subaerial denudation.

The movements are expressed in the deposits, not by folding, but by block-faulting. The faults are countless in number. They vary in magnitude from mere dislocations up to master-faults, several miles in length with throws of four or five thousand feet. Some of the larger faults are marked by crush-belts, hundreds of yards wide, in which the rocks are milled beyond recognition.

The faults appear to belong all to one period of movement. They do not adhere to the directions of strike or dip, but they converge at many points, forming an irregular network which divides up the surface into triangular and quadrilateral blocks of all sizes. The larger blocks, bounded by large faults, are further subdivided by smaller faults.

The movements constitute a system of intense

block-faulting, the differential displacement between adjacent blocks often amounting to several thousand feet. In some districts the faulting is so elaborate that the country may be described as a large kind of fault-breccia.

Each block of territory enclosed by the larger faults develops out into a separate topographic unit —usually a ridge or group of ridges. Some are as large as a town or village, others again no larger than a church or a house.

The attitude of the fault-blocks does not follow any regular plan. Each block has its own independent strike and dip, though a number of neighbouring blocks may differ only slightly in direction.

Near the coast there are some large blocks dipping inland at 25°-35°. Others are inclined to north or south. Inland the blocks have all directions, and the dip varies from 5° to 30°. Near the mountains the blocks generally are tilted seaward at 5°-20°.

Along the edge of the mountains, in the marginal deposits of the Tertiary, there are many small faults which have also disturbed the underlying slates and quartzites; but the more intense faulting occurs at a distance from the old strand-line, and the mountain country probably has been little affected.

This faulting (which is more fully discussed in Part I.) probably is due to a great earth movement, by which the Andes were farther upraised and the ocean floor was farther depressed.

That the ocean bed has subsided, is inferred from the disappearance to westward, of the Tertiary sediments which are exposed on the present coast.

The whole of the Tertiary rocks of this district are shallow-water deposits, and at the present coast their thickness is 15,000-20,000 feet. Therefore they must have extended many miles farther west.

But a few miles westward from the coast, the ocean floor now descends steeply to a great depth—a depth of many thousands of feet below the lowest limit of wave erosion.

The abrupt disappearance, therefore, of the westward continuation of the Tertiary has not been caused by denudation but presumably is due to subsidence; and the part which has subsided probably is far greater in extent than the part which has been lifted up.

That the mountains, at any rate in some parts, have been uplifted 5000-10,000 feet is evident from the present altitude of the strand-lines of the lower members of the Tertiary along the mountain flanks. (The portion of this upraising to be deducted, as being due to the Quaternary movements—which are yet to be described—is comparatively small, varying from 200 to 1200 feet.)

Thus the grand event of this time was a subsidence of the ocean floor 5000-10,000 feet, and an uplifting of the mountains 10,000-20,000 feet.

Between the sunken ocean floor and the upraised mountains, lies the great fault-belt of this movement, with its axis somewhere along the edge of the continental shelf.

The Littoral, with its complicated block-faulting, is a part of the crush-belt of this geo-fault.

The altitude of this new addition to the land

probably amounted, in some parts, to several thousand feet. (See Chap. VIII.)

Igneous activity did not accompany the movements in this district. But in the Santa Elena Peninsula of Ecuador, which is 140 miles north of our special area, many post-Tertiary, but pre-Tablazo, dykes and sills have been intruded among the faulted, and steeply inclined, Tertiary beds.

CHAPTER VIII

POST-TERTIARY SUBAERIAL DENUDATION

After the emergence of the Littoral from the sea, which resulted from the block-faulting, extensive subaerial erosion must have taken place—before the ensuing Quaternary marine transgression could be achieved. For as we travel from the coast to the mountains we may pass, several times, from blocks of the lowest member of the Negritos Formation on to blocks of the Lobitos Formation, which are 5000 feet higher in the stratigraphic column. From these blocks of Negritos Formation thousands of feet of strata must have been denuded.

Probably the uplifting was gradual and much of the denudation was contemporaneous. Yet it is likely that at some time after the deposition of the Tertiary beds and before the deposition of the Tablazo beds, a land surface existed which included hills some thousands of feet high. The areas now exposing the Negritos Formation are the stumps of the loftier ground. One such hill-mass must have occupied some twenty square miles in the district of Punta Parinas; another lay north-west of La Brea; and several other similar masses occurred to northward.

This denudation, and the complete change of fauna, is the record of a long period which elapsed between the block-faulting of the Littoral and the oscillatory movements which have next to be described.

SECTION B

THE MANCORA EPISODE OF THE QUATERNARY PERIOD

CHAPTER IX

COMMENCEMENT OF THE QUATERNARY PERIOD

The deposits which have now to be described differ widely from those of the Tertiary. They are composed of different ingredients; their texture is different; and they contain a different fauna. They are comparatively thin sheets of sediment, lying horizontally over the upturned Tertiary rocks. (See sections, Folder No. V.)

The surfaces of these deposits are known as Tablazos. They are marine terraces, akin to raised beaches, but are of greater magnitude and are more correctly described as raised sea-floors. (See map, Folder No. IV.)

The Tablazos of this part of Peru are smooth tablelands having altitudes ranging from 50 feet to 1200 feet. The thickness of the beds varies from 5 feet to 250 feet.

Even the oldest of these sea-beds is, in large part, perfectly preserved; and together they cover (or recently have covered) almost the whole of the land between the mountains and the sea.

The oldest and highest Tablazo probably belongs to the earliest Quaternary time; but the geological processes which made it are still in action, and the newest Tablazo is that which is being formed at the present time.

The first of the Tablazo formations was laid down on a wide plain of marine erosion which reached almost to the mountains.

It will now be shown that the Tablazos are the consequence of repeated oscillation of a fragment of the earth's crust.

The order of events was as follows:

Aided by a slight and gradual subsidence, the sea advanced upon the land surface, carving out a plain of marine denudation. Simultaneously, in the rear, shell-limestones and sands were being deposited upon this plain, as it sank below the limiting depth of the marine erosion.

Next ensued an uplift movement, which gradually raised the deposit above the sea in the form of a Tablazo. During the uplift the sea gradually retreated; and in its retreat it left behind it a cover of beach material, spread over the whole surface of the deposit.

Then the uplift ceased, and downward motion was resumed. Again the sea advanced against the new-formed land, making rapid progress in its attack. Thus another extensive plain of marine denudation was carved out (at a different level) and another deposit of shell-limestone was formed.

And so also in due sequence came another uplift, bringing up this second deposit as a Tablazo—with

a raised sea-cliff for its eastern edge, dividing it from the sea-floor previously raised.

And in this manner, by the repetition of events, a succession of Tablazos has been produced. The Tablazos are a monument to the efficacy of marine erosion.

CHAPTER X

SUBSIDENCE AND MARINE EROSION DURING DEPOSITION OF THE MANCORA TABLAZO BEDS

THE plane of marine erosion upon which the Mancora Tablazo rests is a flat floor, with but little irregularity. It now extends over a thousand square miles and is clearly exposed, in section, beneath the Tablazo, in the walls of the innumerable quebradas or canyons by which this plateau is dissected.

The full amount of the sea's advance is not known, but all along the 100 miles of the Littoral here discussed it probably exceeded 20 miles. For the initial coast-line of the "Mancora Sea" was some miles west of the present Pacific coast, whilst the final position of the sea-cliffs was fifteen miles inland from the sea-cliffs of to-day.

Under the existing desert conditions subaerial denudation is slow, and does not afford the customary amount of aid to the sea in its attack upon the land.

Thus the erosion of this wide plain by the sea during the Mancora transgression is the more noteworthy and, unless a subsidence of the land was in progress, it would be difficult to explain.

The subsidence, as usual, is less readily proved than are the ensuing uplifts; but we have further evidence, in the deposit which was formed upon the plain of erosion.

This deposit is no less than 250 feet thick at its most western end, becoming gradually thinner when traced inland. The average thickness is perhaps 150 feet.

Even if such a plain of erosion could be produced without the accompaniment of subsidence, it is still inconceivable that such a deposit could grow on it, for we can hardly suppose that the same sea which was cutting the plain out of solid rock was also building up 250 feet of limestone upon it.

But if a gradual sinking of the new sea-floor was also in progress, the deposit is readily understood, for it could accumulate freely up to the amount which would compensate the subsidence.

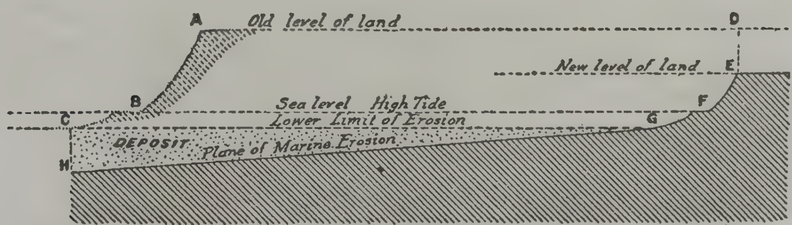


FIG. 26.—Diagram to explain deposition of a Tablazo Bed on a subsiding plane of marine erosion.

T years ago	the land-margin was at	A
,, ,,	the beach-shelf was at	B
,, ,,	the advancing plane of erosion was at . .	C
During T years	the land-margin receded from . . .	A to D
,, ,,	the beach-shelf advanced from . .	B to F
,, ,,	the plane of erosion advanced from . .	C to G.

$$AD = BF = CG.$$

In the same period the earth's crust subsided so that the point D at the top of the cliff was lowered to E, and likewise the point C on the plane of erosion was lowered to H.

$$DE = CH.$$

Thus the plane of marine erosion produced during the T years is represented by the inclined line HG.

Also during this period a deposit has accumulated on this plane, loading it up to the lower limit of marine erosion—the line CG

The thickness of the deposit decreases uniformly as we pass inland.

Thus we have:

(1) The subsidence during the transgression is at least as great as the thickness of the deposit, measured at its seaward boundary.

(2) The inclination of the plane of erosion is the angle whose tangent is $\frac{CH}{CG}$ or $\frac{\text{subsidence}}{\text{transgression}}$ or $\frac{\text{thickness of deposit}}{\text{distance from its inland limit}}$.

In the case of the next Tablazo (Talara Tablazo) an additional piece of evidence of subsidence will be produced.

It is concluded that, erosion, subsidence, and deposition all were in progress simultaneously, for the making of each Tablazo bed.

This is further illustrated in the diagram (Fig. 26).

In the particular case of the Mancora Tablazo, the most western part is that near Cabo Blanco (lat. 30). (maps, Folder IV., and also Folder I. in Part I.)

Here the deposit has a thickness of 250-300 feet; from which it is concluded that the subsidence amounted to at least 300 feet. If more westerly parts of the Tablazo had been preserved, we there might have had evidence that the downthrow exceeded this amount.

At the southern end of the map, in the cliffs at Payta, the thickness of the deposit is 75 feet. Thus, in all probability, the subsidence here was much less than in the Cabo Blanco district. Possibly the subsidence decreased to southward; but of this there is no certainty, as we do not know how much greater was the thickness in the more western parts which have been eroded away by the present sea.

Photograph by O. D. Boggs.

FIG. 27.—View looking down Quebrada Parinas from the mouth of Quebrada Mogollon (13 miles inland) (lat. 11, long. 14).

The whole of the skyline is formed by the flat surface of the Mancora Tablazo. Low-level terraces are well seen; and in the left distance there is a higher terrace. White sand marks the present watercourse. The bushes are *Algarroba*.

Photograph by O. D. Boggs

Fig. 28. View in Quebrada Parinas, 10 miles inland, looking west. (Lat. 11, long. 13.)

The skyline is formed by the surface of the Mancora Tablazo.

Photograph kindly lent by Mr. Beeby Thompson.

CHAPTER XI

EXTENT OF THE MANCORA TABLAZO

The Mancora Tablazo is the oldest and highest of the raised sea-floors. It is wonderfully well preserved, and within our map it still covers some 700 square miles of a strip of country 12 miles wide and 80 miles in length. (See Folder No. IV. and Folder No. V.)

The eastern limit of the tablazo is the old sea-cliff of the Mancora Sea, now about 15 miles inland (later described). The present northern limit is the Quebrada Mancora (lat. 40), which is 50 miles south-west of Tumbes; but the original northern boundary was not found, as there has been deep denudation along the Mancora valley and to northward of it (where the rainfall is not inappreciable). The southern limit to the deposit is beyond the confines of the map. To westward the tablazo formerly continued out for several miles where there is now sea; but as to the original western limit we shall speculate later. (Chap. XVIII.)

The present western edge of the Mancora Tablazo is very ragged. At Cabo Blanco (lat. 30) the tablazo reaches to the sea and forms the great cliffs, about 1000 feet high, which line that part of the coast. At Payta (lat. −29) also, it extends to the sea and caps the sea-cliffs, 200 feet in height. In other parts,

erosion of several kinds has cut back into the old plateau, in places, so that the present western edge is some miles inland.

This erosion has been produced by various agents and at various times. Chief of these was the marine erosion of the next succeeding tablazo episode; that is, erosion by the Talara Sea. This sea cut far into the uplifted deposit, leaving sea-cliffs which are now about ten miles inland and which now have their base 300 feet above sea-level. Also there has been river erosion during floods which recurred at frequent intervals (later to be described). These have cut innumerable deep entrenchments into the tablazo, some of which are now canyons 800 feet deep. Thirdly, wind erosion has worn the tablazo in many places, further fraying its western edge.

CHAPTER XII

THE SHORE LINE OF THE MANCORA TABLAZO

THE old coast-line of the Mancora Sea was traced for a distance of 40 miles, and is shown on the accompanying map. (Folder No. IV.)

This sea in places reached to within about a mile of the mountains, where its beach lay against Tertiary rocks, which remained as a fringe of low hills around the foot of the mountains.

Throughout most of its length the actual cliff and beach line is now but little seen. This is partly because erosion has been severe where the mountain valleys open on to the tablazo plain, and partly because the great Breccia Fan—which has spread out from the mouths of these valleys, now covers a large area of the tablazo as well as the hills of Tertiary rocks. Nevertheless the inland limit can be traced with fair accuracy, and in places the actual shore-line can be seen in the quebrada sections.

The northern shore of the Mancora Sea is unknown, because in the Mancora valley, and to the north of it, the deposit has been removed by denudation.

In the north-east part of the map the shore-line lay 12-15 miles inland, and now has an elevation of about 1200 feet.[1] In the central part of the map it

[1] Many of the altitudes stated, are only approximate.

is 12 miles inland and has an elevation of 400-500 feet.

South of the Amotape Mountains the coast-line has not been traced, but the normal tablazo extends at least 12 miles inland, with elevation about 250 feet. Here the marine deposit merges into what is probably an estuarine and river deposit, which continues inland a farther 35 miles. It appears that there was a large bay of the Mancora Sea between the Amotape Mountains and the Payta Mountains; and that into this a rather large river flowed, which came from the more distant mountains north-east of Piura.

To southward the sea continued beyond the limits of the area now discussed.

Photograph by T O. Bosworth.

FIG. 30.—A small section in the Mancora Tablazo bed close to its shore-line, 18 miles inland, east from Lobitos at "La Penita." (Lat. 16½, long. 23½.)

The massive character of the pebble-shell-limestone is well displayed.

CHAPTER XIII

THICKNESS OF THE MANCORA TABLAZO BED

TOWARDS its northern end, where the Mancora Tablazo bed is well exposed in the massive sea-cliffs of the Cabo Blanco district (lat. 30 to lat. 25), a thickness of 250-300 feet is seen.

Thence southward the deposit thins steadily. Around Quebrada Collonitas (lat. 20) the sections show it to be 180 feet thick, and in Quebrada Parinas (lat. 10) a thickness of 100 feet is found. Just south of Quebrada Ancha (lat. 3) the thickness of this deposit has diminished to only 15 feet, but this is partly due to irregularity in the floor, for the pre-tablazo block-faulting had brought up a mass of sandstone here, which was not easily planed down by the marine erosion, and probably for a long time was an island in the Mancora Sea.

Continuing southward the thickness quickly increases again to 60 feet or more, and along the north side of the Chira valley (lat. −15) the tablazo is 120 feet thick. Farther south the amount of the deposit diminishes, so that at Colan (lat. −23) the thickness is 100 feet; and at Payta (lat. −29) it is further reduced to 75 feet.

In the south-east of our map, extending to 50 miles inland, there are horizontal shales, sandstones, and conglomerates, several hundred feet thick, which probably are an estuarine arm of the Tablazo bed.

CHAPTER XIV

THE PEBBLES OF THE TABLAZOS

Pebbles are one of the chief ingredients of the Tablazo deposits. There are three distinct classes of pebbles ; most often they occur in different beds.

1. The Andean Stones.—These are present in enormous quantity, both in regular pebble beds and distributed in the other sediments. Though the bulk of them are under 3 inches or 4 inches in diameter, they occasionally measure as much as 7, 8, 9 inches or more.

They are typical beach pebbles (see Fig. 31); perfectly smoothed, flattened, and rounded. Those lying on the surface of the Tablazo are mainly black, greenish black, green, and dark red. They have been split up by the sun, and cut and polished by blown sand (Fig. 32). But when broken open or when taken from inside the deposit, many are green, brown, bluish, and red, etc. They are andesites, basalts, porphyrites, vesicular rocks, ashes, together with a smaller proportion of quartz and other hard rocks.

These stones are derived from mountains beyond our map, to the south-east, where identical pebbles are now being produced from igneous masses of this character.

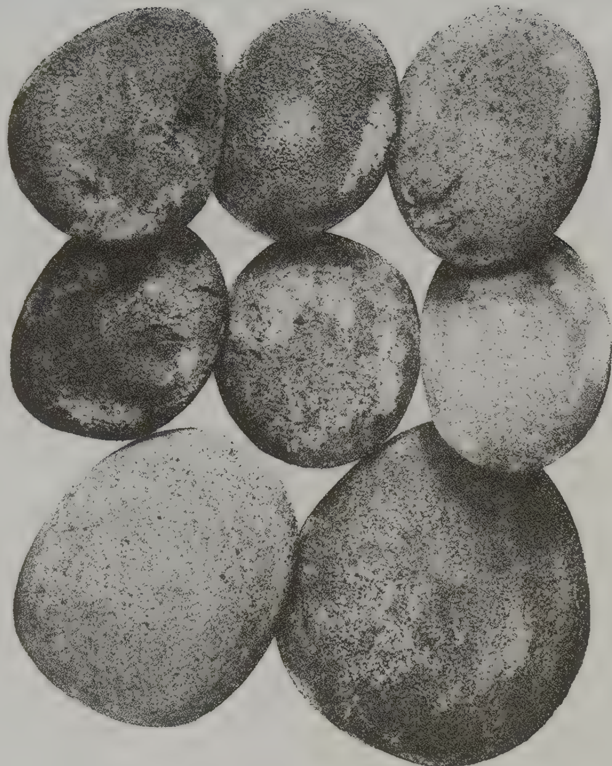


Fig. 31.—Andean pebbles from within the Tablazo beds Sample taken at a depth of 6 inches. (Reduction = ½ natural size.)

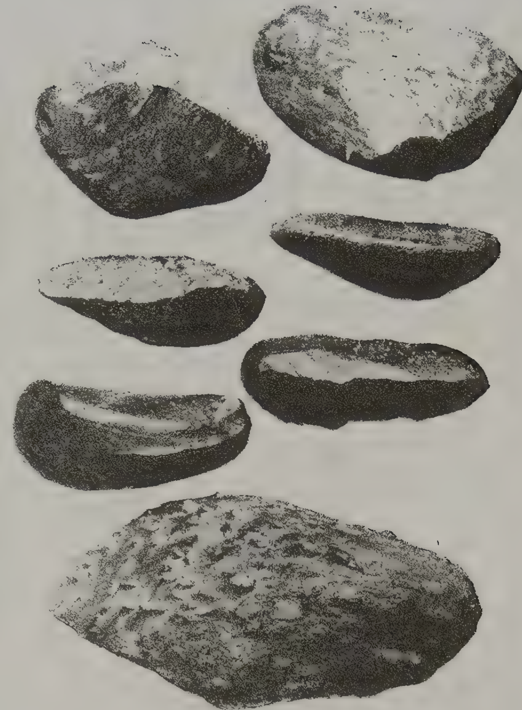


Fig. 32.—Andean stones from surface of the Tablazo beds. Sample taken from the surface at same locality as the pebbles shown in Fig. 31. (Reduction = ½ natural size.)

These angular stones have been carved out by wind erosion, from pebbles similar to those shown above.

2. The Amotape Stones. — Some beds of the Tablazo, especially in the north and inland, contain a large quantity of stones derived from the Amotape Mountains. These are perfectly distinct from the Andean stones. They are angular or subangular in shape and occur in all sizes up to blocks a foot or two in length, these larger specimens being plentiful at the base of the deposit near its inland limit.

The Amotape stones consist mainly of quartzite, with rusty-brown surface, streaked with white veins of quartz, and slates of dark colour. Spotted slate also is present in abundance, and coarse white granite is present in small quantity.

3. Tertiary Stones.—These are pebbles derived from the pebble beds in the Tertiary. They are smooth and very much rounded or flattened. Most abundant are: quartz, quartz-schist, quartzite, porphyrite (pale), andesite (pale), basalt.

With these stones we must also include blocks of calcareous Tertiary sandstone, which often are found at the base of the Tablazo deposit.

CHAPTER XV

THE FOSSILS OF THE TABLAZOS

Marine fossils are present on and in the Tablazo beds in immense quantity, though the number of species is not great (Plates XXV. and XXVI.). The shells are not at all mineralised, as a rule, and often some of their colouring is preserved. Many of the common species are large, and are so strong that they have not been broken although they are mixed with large stones.

Conspicuous among the shells are large barnacles, up to 6 inches in length and 3 inches diameter, some of the limestones in the Talara Tablazo being almost entirely composed of them (Fig. 42); large *Pectens*, 3-4 inches across, often making a shell limestone; banks of great round oysters, of 6-10 inches diameter; large *Arcas*, 2½-6 inches across; and *Turritellas*, 5-8 inches in height.

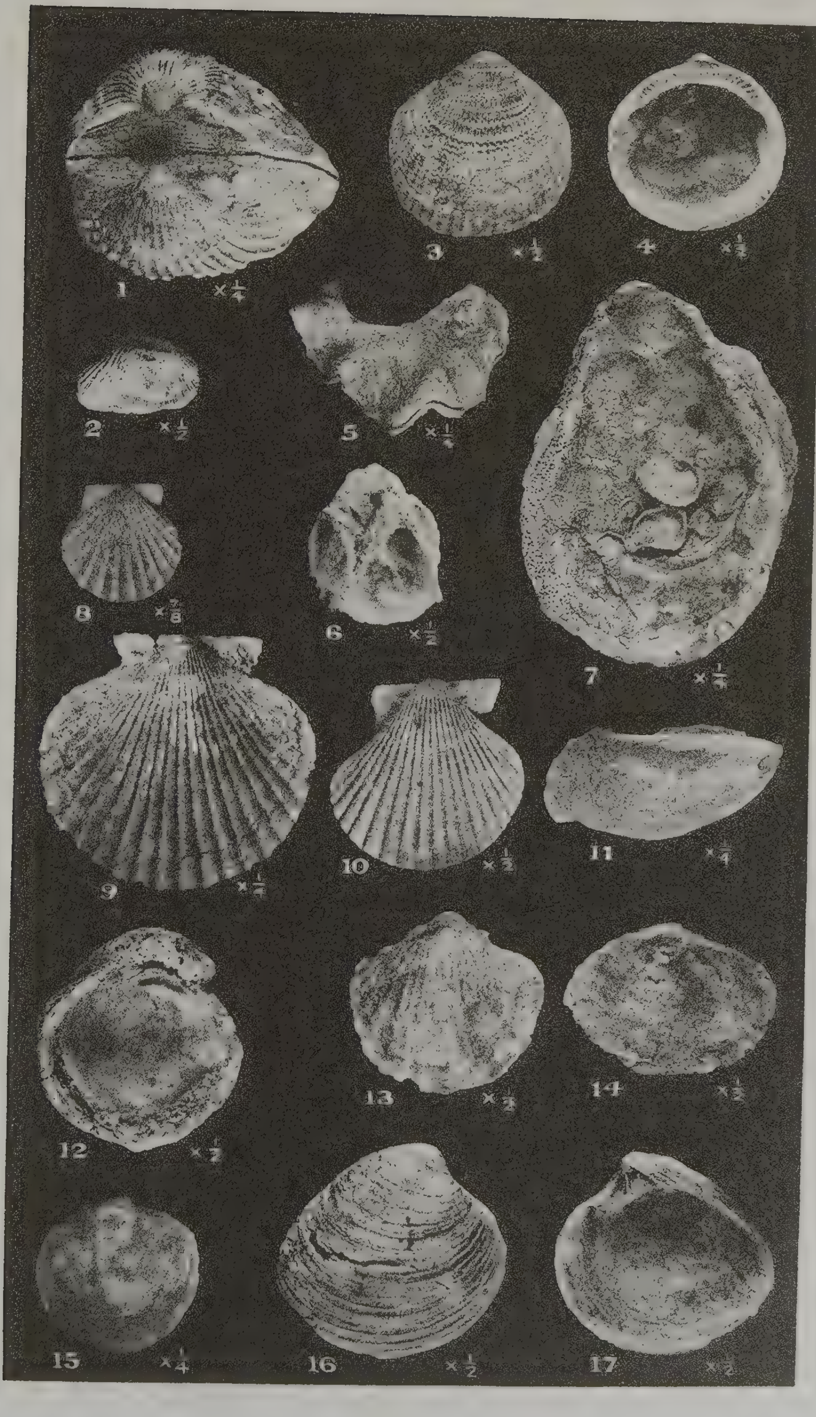
Most of the shells collected are abundant, and range over the whole tablazo; but their relative proportion is notably irregular, so that the shell limestone often may consist almost wholly of a single species. In other cases, where the different kinds of shells are mixed together, some one of the commonest species may be conspicuously absent.

Coral mounds, several feet in diameter, occur in

PLATE XXV.—FOSSILS OF THE TABLAZO BEDS—Pelecypods.

EXPLANATION OF PLATE XXV.

No.	1. *Arca grandis*, × ½.	Specimen from	Mancora Tablazo.
,,	2. *Arca illota*, × ½	,, ,,	Lobitos Tablazo.
,,	3. *Glycimeris ovata*, × ½.	,, ,,	Talara Tablazo.
,,	4. ,, ,,	,, ,,	,, ,,
,,	5. *Ostrea megodon*, × ½.	,, ,,	Talara Tablazo.
,,	6. *Ostrea equatorialis*, × ½.	,, ,,	Talara Tablazo.
,,	7. *Ostrea* sp., × ½	,, ,,	Talara Tablazo.
,,	8. *Pecten tumbezensis*, × ½.	,, ,,	Talara Tablazo.
,,	9. *Pecten purpuratus*, × ½.	,, ,,	Mancora Tablazo.
,,	10. *Pecten ventricosus*, × ½.	,, ,,	Talara Tablazo.
,,	11. *Mytilus chorus*, × ½	,, ,,	Mancora Tablazo.
,,	12. *Chama pellucida*, × ½.	,, ,,	Mancora Tablazo.
,,	13. *Anomia peruviana*, × ½.	,, ,,	Talara Tablazo.
,,	14. ,, ,,	,, ,,	,, ,,
,,	15. *Cyclinella subquadrata*, × ½.	,, ,,	Mancora Tablazo.
,,	16. *Chione compta*, × ½.	,, ,,	Talara Tablazo.
,,	17. ,, ,,	,, ,,	,, ,,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large radiating masses, of hemispherical shape. These, in position of growth, are specially plentiful on the north-western part of the Mancora Tablazo, where pebbles are less numerous.

Large bones of whales are fairly frequent, and in one or two places there are skeletons, more or less entire.

The Gasteropoda and Lamellibranchiata have been examined by Lt.-Col. A. J. Peile, and the Cirripedia by Mr. T. H. Withers, F.G.S. Almost all of the shells were identified with species still living on the present coast; and probably the two or three others, later, will likewise be identified.

The faunas of the two older tablazos, as shown by the following table, are practically identical; but the Lobitos Tablazo contains many additional species. This is due to an interesting change in the geography of the coast-line.

At the present time the cold Humboldt Current, coming from the south, which washes the Peruvian coast, is turned westward as it passes the promontory of Punta Parinas and Cabo Blanco; whilst farther northward the coast is warmed by the current which flows south from Ecuador.

In the present fauna, a sharp change marks this difference in the water; so that, from about Lobitos northward, there is, upon the shore, an abundance of species that are not conspicuous on the shore immediately southward.

It was just such conditions that enriched the fauna

of the Lobitos Tablazo. For, as shown on the map (Folder IV.), the coast of the Lobitos Sea presented a promontory to the ocean, north of Negritos, which doubtless turned the water of the Humboldt Current of that time westward, just as it is turned to-day. (In the Talara and Mancora Seas the configuration of the coast was not the same.)

And so it is that, in the northern part of the Lobitos Tablazo, many additional species of shells were found.

List of Identified Species on the Tablazos.

The following is a list of the shells from the Quaternary Marine Terraces which have been identified. There are a few others which have not yet been determined, and also many more would be obtained by systematic collecting.

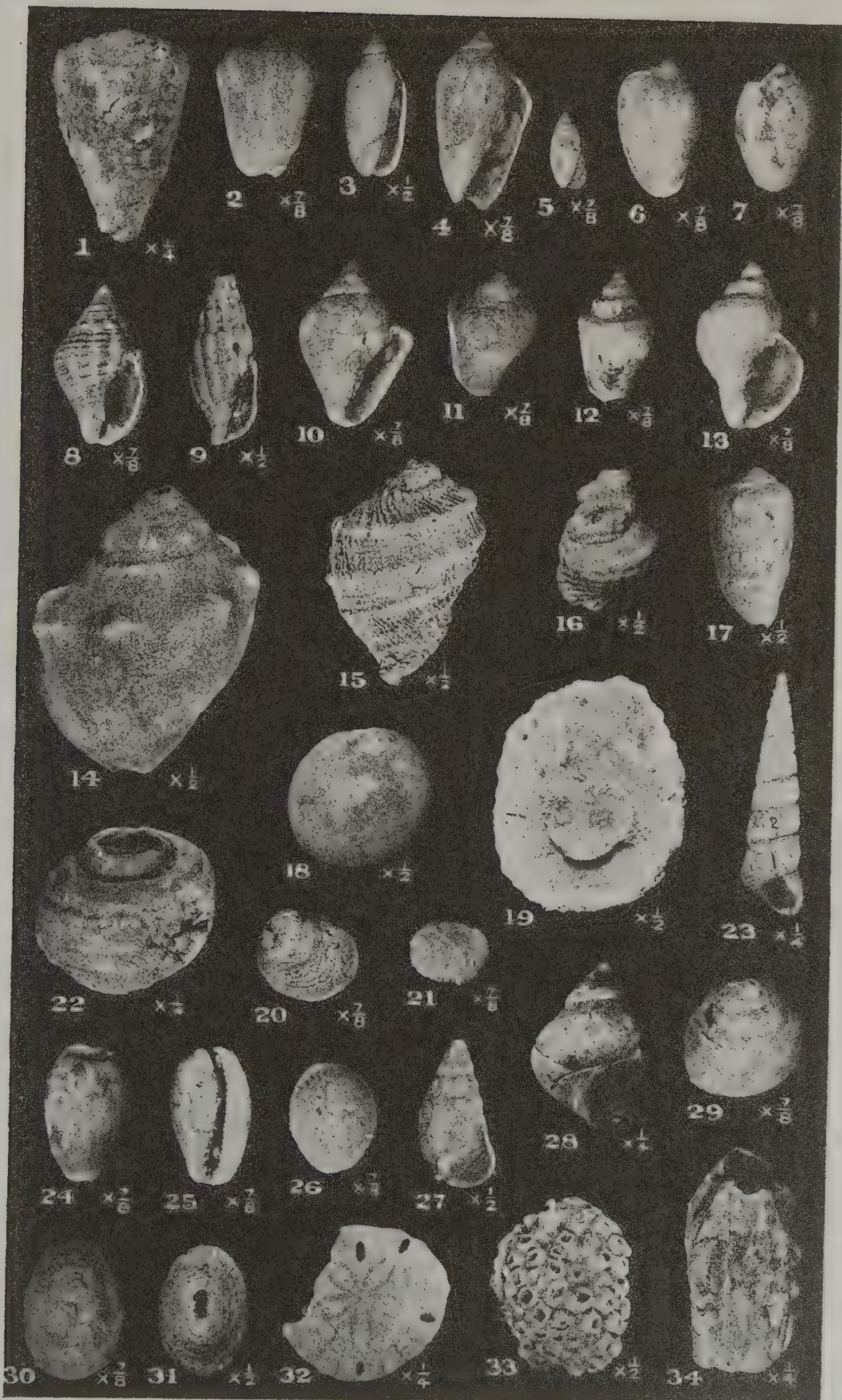
All of the shells identified are living species, and all but two of them are listed in the report on a collection of shells from Peru, by Professor W. H. Dall, published in *Proc. U.S. Nat. Mus.* vol. xxxvii., November 1909.

[Table

PLATE XXVI.—FOSSILS OF THE TABLAZO BEDS—Gasteropods, etc.

EXPLANATION OF PLATE XXVI.

No	1.	*Conus fergusoni*, × ½.	Specimen	from	Lobitos Tablazo.
,,	2	*Oliva peruviana*, var., × ¾.	,,	,,	Mancora Tablazo.
,,	3.	*Oliva reticularis*, × ½	,,	,,	Lobitos Tablazo.
,,	4.	*Oliva peruviana*, × ¾.	,,	,,	Mancora Tablazo.
,,	5	*Olivella columellaris*, × ¾.	,,	,,	Mancora Tablazo.
,,	6.	*Marginella curta*, × ½	,,	,,	Lobitos Tablazo.
,,	7.	*Marginella sapotilla*, × ¾.	,,	,,	Lobitos Tablazo.
,,	8.	*Cantharus gemmatus*, × ¾.	,,	,,	Lobitos Tablazo.
,,	9.	*Mitra lens*, × ½.	,,	,,	Lobitos Tablazo.
,,	10.	*Columbella strombiformis*, × ¾.	,,	,,	Lobitos Tablazo.
,,	11.	*Columbella labiosa*, × ¾.	,,	,,	Lobitos Tablazo.
,,	12.	*Columbella paytensis*, × ¾.	,,	,,	Lobitos Tablazo.
,,	13	*Thais delessertiana*, × ¾.	,,	,,	Mancora Tablazo.
,,	14.	*Thais chocolata*, × ½.	,,	,,	Mancora Tablazo.
,,	15.	*Acanthina muricata*, × ½.	,,	,,	Talara Tablazo.
,,	16	*Distortio constrictus*, × ½.	,,	,,	Lobitos Tablazo.
,,	17.	*Morum tuberculosum*, × ½.	,,	,,	Lobitos Tablazo.
,,	18	*Sinum cymbium*, × ½.	,,	,,	Mancora Tablazo.
,,	19	*Crucibulum imbricatum*, × ½.	,,	,,	Lobitos Tablazo
,,	20.	*Hipponix barbata*, × ¾.	,,	,,	Lobitos Tablazo.
,,	21	*Crepidula aculeata*, × ¾.	,,	,,	Mancora Tablazo.
,,	22	*Malea ringens*, × ½	,,	,,	Mancora Tablazo.
,,	23	*Turritella goniostoma*, × ½.	,,	,,	Talara Tablazo.
,,	24.	*Cyprea nigropunctata*, × ¾.	,,	,,	Lobitos Tablazo.
,,	25	,, ,,	,,	,,	,, ,,
,,	26.	*Trivia radians*, × ¾.	,,	,,	Lobitos Tablazo.
,,	27.	*Cerithium adustum*, × ½.	,,	,,	Lobitos Tablazo.
,,	28	*Turbo magnificus*, × ¾.	,,	,,	Lobitos Tablazo.
,,	29.	*Tegula panamensis*, × ¾.	,,	,,	Mancora Tablazo.
,,	30.	*Fissuridea inæqualis*, × ¾.	,,	,,	Mancora Tablazo.
,,	31.	*Fissurella virescens*, × ½.	,,	,,	Lobitos Tablazo.
,,	32.	*Echinoid*, × ½	,,	,,	Talara Tablazo.
,,	33.	*Balanus lævis*, × ½.	,,	,,	Mancora Tablazo.
,,	34.	*Balanus tintinabulum*, var. *concinnum*, × ¾.	,,	,,	Mancora Tablazo.



FOSSILS ON THE TABLAZOS.

Species living on the present coast, but recorded only in the northern or warm-water portion of it.	Mancora Tablazo.	Talara Tablazo.	Lobitos Tablazo.
GASTEROPODA			
Oliva reticularis. Lam.			a
Marginella sapotilla. Hinds.			o
Cantharus gemmatus. Rve.			a
Columbella labiosa. Sow.			a
Acanthina muricata. Brod.			
Distortio constrictus. Brod.			o
Cerithium adustum. Kien.			a
Hipponix barbata. Sow.			a
Fissuridea inæqualis. Sow.	o		a
PELECYPODA			
Arca illota.† Sow. (prob.)			o
Cyrena anomala. Desh.			o
Cyclinella subquadrata. Hanl.	a		

Species living on present coast, but recorded only in the southern or cool-water portion of it.	Mancora Tablazo.	Talara Tablazo.	Lobitos Tablazo.
GASTEROPODA			
Thais chocolata. Ducl.	a	a	a*
PELECYPODA			
Glycimeris ovata. Brod.	a	a	
Ostrea longiscula. Hupé.	a		
Mytilus chorus. Mol.	a		

"o" indicates species occurs.
"a" indicates species occurs abundantly.
* indicates the occurrence was in a southern remnant of the Lobitos Tablazo, 7 miles S.E. of Punta Parinas, 2 miles inland, altitude 15 feet.

† Not in Dall's list. Brit. Mus. specimens from Gulf of California. Found in Galapagos Is.; Mazatlan, La Paz, *fide* Tryon.

FOSSILS ON THE TABLAZOS—*continued.*

Species living on present coast and recorded both northward and southward.	Mancora Tablazo.	Talara Tablazo.	Lobitos Tablazo.
GASTEROPODA			
Conus fergusoni. Sow. (prob.)	a		a
Oliva peruviana. Lam.	a	a	a
Olivella columellaris. Sow.	o		
Marginella curta. Sow.			o
Mitra lens. Mawe.			o
Columbella paytensis. Less.			a
Columbella strombiformis. Lam.			a
Thais biserialis, var. Blain.			a
Morum tuberculosum.† Sow.(prob.)			a
Malea ringens. Swain.			o*
Cypræa nigropunctata. Gray.			a
Trivia radians. Lam.			a
Turritella goniostoma. Val.	a	a	a*
Crucibulum imbricatum. Sow.			o
Crepidula aculeata. Gmel.			
Sinum cymbum. Mke. (concavum. Lam. ?)	a	a	o*
Turbo magnificus. Jonas.			o
Tegula panamensis. Ph.			a
Fisurella virescens. Sow.			a
PELECYPODA			
Arca grandis. Brod. and Sow.	a	a	a
Arca tuberculosa. Sow.		o	
Ostrea equatorialis ? Orb.		a	a
Ostrea sp. (v. large)	a	a	
Ostrea megodon. Hanl.	o	a	o*
Pecten purpuratus. Lam.	a	a	
Pecten tumbezensis. Orb.		a	a
Pecten ventricosus. Sow.		a	a
Anomia peruviana. Orb.	o	a	a
Chama pellucida. Brod.			o
Chione compta. Brod.	a	a	a*
Semele solida. Gray.			o
Tagelus dombeyi. Lam.			o
OTHER ANIMALS			
Balanus tintinnabulum, var. *concinnum*	a	a	a
Balanus lævis.	a	a	a
Echinoid (sp. irregular)	a	a	a
Coral	a	a	
Whale	o		

"o" indicates species occurs.
"a" indicates species occurs abundantly.
* indicates the occurrence was in a southern remnant of the Lobitos Tablazo, 7 miles S.E. of Punta Parinas, 2 miles inland, altitude 15 feet.

† Not in Dall's list. Brit. Mus. specimens from Central America, Gulf of Nicoiya.

The Barnacles.

The Cirripedia were examined by Mr. Thomas H. Withers, F.G.S., who made the following report [1] on them :

The barnacles submitted to me by Dr. Bosworth comprise two species only. They occur in great numbers in marine terraces whose altitudes range up to about 1200 feet, some beds being composed of them. (See Plate XXVI. and Fig. 42.)

Balanus (Megabalanus) tintinnabulum, var. *concinnus* (Darwin).

1854. Darwin, *Ray Soc. Monograph Cirripedia, Balanidæ*, p. 196, Pl. I. Fig. *e*, Pl. II. Fig. 1*g*.
1903. Gruvel, *Nouv. Archives du Muséum*, Paris, 4 sér. vol. v. p. 126.
1909. Pilsbry, *Proc. U.S. Nat. Mus.* vol. xxxvii. p. 65, Pl. XVI. Fig. 3, Pl. XVIII. Figs. 5-8.
1916. Pilsbry, *Bull. 93, U.S. Nat. Mus.* p. 69, Pl. XVI. Fig. 3, Pl. XVII. Figs. 5-8.

Distribution.—(Recent) Straits of Magellan to Peru.[2]

Remarks.—Darwin (1854, p. 196) based this variety on specimens from the west coast of South America ; Gruvel (1903, p. 126) recorded it from the Straits of Magellan ; and Pilsbry (1909, p. 65 ; 1916, p. 69) described specimens from Pascamayo and Payta, Peru—one of these taken from a wreck at Payta, had a length of 150 mm. Gruvel (1903, p. 126) also recorded this form from Aden and the French Congo, but Pilsbry suggested that probably the specimens had been taken to those places by ships.

Except for individual differences the specimens from the several Quaternary deposits do not appear to differ materially from each other, but in all the terga the crests for the lateral depressor muscles are well developed, which is not the case with recent specimens. The largest shell has a length of about 110 mm.

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[1] By permission of the Trustees of the British Museum.

[2] It occurs also along the coast of Ecuador both on present beach and in Tablazos. [Note by Author.]

Pilsbry (1909, p. 65) stated: "This is a common barnacle in all warm seas, probably derived from an oriental center. It is one of the most abundant forms carried on ship bottoms. Whether it reached the west coast of South America by natural means, or was carried there by commerce, has not been ascertained. If it proves to be wanting in pleistocene or pliocene deposits of the west coast, the theory of recent introduction may safely be held."

The present occurrences are opposed to the theory of recent introduction.

Balanus (Balanus) *lævis*, var. *nitidus* (Darwin).

1854. Darwin, *Ray Soc. Monogr. Cirripedia, Balanidæ*, p. 227, Pl. iv. Fig. 2.
1909. Pilsbry, *Proc. U.S. Nat. Mus.* vol. xxxvii. p. 68, Pl. xvii., Pl. xix. Figs. 5-9.
1916. Pilsbry, *Bull. 93, U.S. Nat. Mus.* p. 122, Pl. xxvii. Figs. 2-2*d*, 4, 5.

Distribution.—(Recent) Concepcion, Chile, to Peru.

Remarks.—The specimens in the several Quaternary deposits do not appear to differ from recent specimens; in all those examined the scuta show two strongly marked, but narrow, longitudinal furrows characteristic of this variety.

CHAPTER XVI

CHARACTER OF THE MANCORA TABLAZO DEPOSIT

THE STRATA.—The tablazos are calcareous formations consisting of shell-rocks, limestone, pebble beds, marls, calcareous sands and sandstone. All of the beds are white or yellowish white.

The stratigraphy of this deposit varies so much that sections taken only a mile apart may differ widely; but always the predominant rock is a pebbly shell-limestone. A peculiarity of the formation is the intimate association of pebbles with lime.

The principal kinds of rock in the tablazos are further described below:

The **Limestone** occurs in massive beds, single courses sometimes having a thickness of 30 feet. Commonly it breaks down from the cliffs in immense blocks. In parts the rock is hard enough to make a fair building stone, but more often, for lack of cement, it breaks up or crumbles up rather easily.

In some respects the rock resembles some of the Jurassic limestones of Britain, being composed of shells and shell fragments loosely packed together. But this limestone is peculiar in that it encloses a large quantity of stones, which are present not only in irregular bands and seams but chiefly as an

ingredient liberally besprinkled all through the rock. In some cases these stones may amount to one-third the substance of the limestone. Some sand also is included.

The stones in the limestone are generally the Andean beach pebbles, measuring up to 3 inches or 4 inches; and often larger; but there are some beds which contain the Amotape stones; and occasionally there is a mixture of all the different kinds.

The presence of the stones in quantity does not affect the other constituents of the limestone. All the species of shells occur profusely intermingled with the stones, so that often the rock might be equally well described as a shelly calcareous conglomerate or a pebbly shell-limestone.

The limestones vary much in regard to the shell material of which they are composed. One of the commonest rocks is a *Balanus* limestone (cf. Fig. 42). This consists almost wholly of barnacles, together with some pebbles. The barnacles occur as individuals and also in clusters. Most of them are large, many being several inches in length and one or two inches wide. *Pecten* limestone also is abundant. In this case the rock consists of large *Pectens* and some pebbles, together with broken shell material just sufficient to hold them together. In other cases the limestone may contain *Glycemeris* and *Chione* in such quantity as to almost exclude the other species. In some places again, the crescentic oyster (*O. megodon*) or one of the larger oysters is predominant; and occasionally the *Mytilus* or *Arca*, or even the *Turritella*, is the most noticeable constituent of the rock.

Photograph by O. D. Boggs.

Fig. 33.—Section of the Mancora Tablazo beds, in the cliffs of Quebrada Parinas. (Lat. 12, long. 15.)

On both sides of the valley the flat surface of the Tablazo forms the skyline. The watercourse is occupied by white sand and is flanked by a belt of Algarroba bushes. Extensive terraces are visible on the far side.

Photograph by O. D. Boggs.

FIG. 34.—Section showing Mancora Tablazo bed overlying the Tertiary, in cliff of Quebrada Salado. $2\frac{1}{2}$ miles from its junction with Quebrada Parinas. (Lat. 8, long. 14.)

In the presence of moisture the tablazo limestone undergoes an interesting change.

Thus in the cliffs along the verdant valley of the Rio Chira, the rock is compacted together with a semi-crystalline calcareous cement, which renders it much harder and gives it a much older appearance. Also the fossils are preserved as casts, and some care is necessary to identify these with the normal shells.

In the moist climate of Ecuador, the tablazo limestones have this same character.

There is another mode of occurrence of this crystalline limestone which is clearly the result of water action. Thus when a limestone at the surface overlies a loose pebble bed, often there are cylindrical growths, several inches, or a foot or two, in length, depending down into the bed below. These pendants are composed of hard semi-crystalline limestone of the type described above.

The **Marls** and **Marly Shales** are yellowish, white or greenish-white, and are composed largely of material from the Tertiary clay-shales. They contain few shells, and pebbles in them are rare.

The **Calcareous Sandstone** and the sands also are white or yellow. They contain some shells; but these are more broken, and are not so well preserved as in the limestones and pebble beds. Some of the calcareous sands are made of comminuted shells. There is current bedding in these rocks.

Pebble Beds are important members among the strata which make up the tablazos. Most often the

topmost layer of the tablazo is a bed of pebbles, 5 feet to 15 feet thick; and often one or more additional pebble beds occur lower down, alternating with the other strata. Mixed with the pebbles are shells, especially *Pecten* and *Ostrea*, and also some sand.

Most of the pebble beds consist of the Andean stones. The stones at the top of the tablazo invariably belong to this class. Some of the pebble beds within the formation, however, consist of worn Amotape stones, and there is sometimes a mixture of the two kinds. Some of the pebbles derived from the Tertiary, also commonly are present with the others, but it is not always easy to be sure of these.

The thickness and character of the beds and the size of the stones vary much from place to place. The stones generally are less than 4 inches or 5 inches across. Sometimes they are smaller, and occasionally they are considerably larger.

The most constant pebble bed lies on the top of the tablazo. This surface bed, of Andean stones, is obviously a beach which was formed as the sea withdrew, or in other words, as the tablazo emerged. The other seams also probably were beaches, caused by temporary minor upliftings which interrupted the course of the general subsidence.

In the surface pebble-bed there often is a rough white calcareous cement, caused by lime having been drawn up from underlying limestone by the insoaking of water during floods, and its subsequent evaporation at the surface. (This substance is dug out by the natives, and is used for lime, whitewash, plaster, etc.)

At the base of the tablazo there is commonly an irregular and discontinuous bed or seam of stones,

which may include pebbles of all kinds and blocks of the local Tertiary rocks.

Approaching the inland edge of the tablazo, no conspicuous change occurs in the deposits. There is some increase in the amount of sand and local stones (Amotape and Tertiary), but the shell-pebble-beaches and the shell-limestones persist almost right to the old sea cliff. Near the mountains larger blocks of quartzite and spotted slate occur at the base of the deposit, along its coast-line.

The most pebbly development of the tablazo observed, is in the territory immediately south of the Rio Chira. Thus at Colan (lat. −23, long. 18) there are several Andean pebble beds, 10-15 feet thick, making up a large part of the total thickness of 100 feet. Likewise at Arenal (lat. −15, long. 21), on the south bank of the Chira valley, similar thick pebble beds are exposed. It is probable that the rather important river which brought the Andean pebbles to the Mancora Sea, made its entrance in this vicinity.

South of the Rio Chira, the tablazo extends inland in the form of a large embayment, having the Amotape Mountains to the north of it and the Payta Mountains to the south of it. The shell-limestones continue to be exposed at the surface as far inland as the east boundary of our area (Map No. 1), which is 12 miles inland or 16 miles east of Payta.

Beyond this the plain continues a farther 40 miles inland (see map, Folder No. I., in Part I.), across the Rio Piura, to the distant mountains (Cerro Ereo, etc.). This region was only briefly traversed, but several points of importance to this discussion were observed.

In this plain, which has an elevation rising from 250 to 400 feet or more, exposures are few, but it appears to be occupied by horizontal sandstones, shales and conglomerates, and pebble beds, which are probably an estuarine extension of the marine tablazo bed.

These pebble beds consist of Andean pebbles, and are identical in character with the pebble beds found in other areas of the tablazo. Limestones and fossils, however, are absent in most of the exposures; though at one place on the east side of the Rio Piura, 36 miles east of Payta, some shell-limestone of the usual type was found. Here there is a little plateau, 220-250 feet above sea-level, capped by a 2-feet bed of large, long oysters similar to those common in the tablazo. A few other shells are present but are not the familiar species.

Continuing farther inland, the pebbles abound; and at length we reach the mountains of igneous rocks which were their source.

It is concluded that an important river, from these mountains, flowed across this area into the Mancora Sea. The Andean pebbles, which are so abundant in the tablazos, all the way from Payta to Mancora, decreasing northwards, presumably were brought into the sea by this river. They were then distributed northward, along the coast, by the shore-drift due to the Humboldt current of that time.

Sections.

The following three sections are given to illustrate the nature of the Quaternary formations. One is in

the north part of the region discussed; one is in the middle; and one is in the south part.

Section at Cabo Blanco (lat. 28).

In this district the cliff section shows 1000 feet of rocks.

Mancora Tablazo Beds—250-300 feet.
Mainly shell-limestone, in courses 20-30 feet thick. Much of it crowded with shells and including quantities of Andean beach pebbles up to 4 inches, and some parts containing Amotape stones. Also marls, calcareous sandstones, and pebble beds several feet thick.

Tertiary—700 feet.
Clays and shales.

Section at Quebrada Salado (lat. 9, long. 13).

In this tributary canyon, which enters the Quebrada Parinas from the south, we have the following section (see Fig. 34). This is within two miles of the old shore-line, and one of the features of the deposit here is the presence of the Amotape stones in the limestone. The rock contains shells in much quantity, some parts consisting largely of *Pecten*, 2-5 inches in diameter, whilst some smaller portions are crowded with *Mytilus*, 4-8 inches long. The tablazo surface here is 460 feet above sea-level.

Mancora Breccia Fan—2 feet.	
Angular Amotape Stones, chiefly quartzite and spotted slate, with a little granite.	2 feet.
Mancora Tablazo Beds—100 feet.	
Sandy Marl, yellowish, with some harder limestone seams. Very few shells or stones.	30 feet.
Shell-Limestone, massive, containing a quantity of worn Amotape stones measuring up to 3 inches.	25 feet.
Marl-Shale, soft and well bedded.	15 feet.
Pebble-Shell-Rock with Andean pebbles.	2 feet.
Clay-Shale, calcareous, well bedded.	8 feet.
Calcareous Sandstone, nearly white, with some shells and stones—stones are both Andean and Tertiary.	10 feet.
Shell-Limestone, massive, with Andean pebbles and Amotape stones. In the lower part there are large Amotape stones, some measuring 2 feet. They are quartzite, spotted slate, etc. Shells are present, even with these.	10 feet.
Tertiary (*Inclined Strata*)—45 feet.	
Clay shales.	45 feet.

SECTION AT PAYTA (lat. – 29, long. 14).

Here there is a sea-cliff section, 200 feet high. In this section no thick pebble beds occur, although it is only six miles from Colan, where they are so strongly developed. The Amotape stones are quartzites and spotted slates, probably from Cerros de Payta. The stones at the base include blocks of Tertiary rock, Andean pebbles, and slabs of spotted slate, quartzite, and decomposed granite (Fig. 29).

Mancora Tablazo Bed—75 feet.	
Shell-Limestone with Andean pebbles and many fossils, chiefly *Chione*, *Thais*, *Turritella*, *Oliva*, etc.	7 feet.
Fine Sandy Marl and Marl-Shales, with stones in some parts.	28 feet.
Seam of Amotape Stones, angular.	—
Sandy Shell-Limestone, soft.	5 feet.
Seam of Amotape Stones, angular.	—
Marls and Calcareous Sands.	9 feet.
Shell-Limestone.	6 feet.
Soft Yellowish Sandstone.	9 feet.
Seam of Amotape Stones, up to 9 inches.	—
Marls and Sands, grey, greenish and yellowish, with mixed stones near the base, measuring up to 9 inches.	11 feet.
Tertiary (*Inclined Strata*)—125 feet.	
Clay shales.	125 feet.

CHAPTER XVII

THE MANCORA TABLAZO SURFACE

HUNDREDS of square miles of the Mancora Tablazo surface remain unimpaired. In some localities stunted shrubs are growing on it, and certain parts also are covered with dunes. But generally there is no cover of sand, and the surface is swept bare by a strong wind. It is possible to ride for miles upon this old sea-floor, almost as level as a gravel tennis-court, and in some parts almost equally smooth. But generally before going very far, progress is suddenly interrupted by some deep quebrada (canyon), with vertical sides. These quebradas have been cut down into the Tertiary rocks beneath, and consequently geological maps on the 6-inch scale have a very intricate appearance.

In the north part of the tablazo area the dissection is intense and deep, but it has not been mapped in detail. The southern portion, however, is but little cut up except at its edges.

In the ground from which the tablazo bed has been removed by subaerial denudation, there are many ridges and hills which still rise to tablazo level and are capped by the remains.

A large portion of the whole tablazo surface is covered over by the Mancora Breccia Fan, 1-100 feet thick; and in these parts the tablazo bed is

exposed only in the innumerable quebradas which have cut through the fan.

The surface of the tablazo is interesting to walk upon. At a distance it has the appearance of brown or yellowish land, recently ploughed and harrowed; but a closer view shows the ground to be fairly hard, and strewn all over with countless stones and shells. Commonly the topmost seam of the tablazo is a bed of beach-stones, 1-10 feet thick, but in other parts a pebbly shell-limestone forms the surface.

The stones are smooth beach-pebbles, measuring up to 2 inches or 3 inches in diameter. As a rule the most numerous are andesites, basalts, and porpherites. Lying on the surface, they have been highly polished by the blown sand, the most prevalent colour being a lustrous black. Many have been split up into fragments by the heat of the sun, and also have been cut by the blown sand into peculiar shapes.

The sea shells are not mineralised and are in good preservation, often retaining some of their colour. The species on the surface are the same as within the deposit. They occur in remarkable profusion—pectens, oysters, gasteropods, barnacles, masses of coral, here and there an echinoid, and occasionally the bones of whales. In two instances more or less complete skeletons have been found.

CHAPTER XVIII

THE ORIGINAL WESTERN LIMIT OF THE MANCORA TABLAZO DEPOSIT

ALREADY we have traced the shore-line of the Mancora Sea, and we have seen that the tablazo bed, which it deposited, once covered all of the land now existing between that old shore-line and the present Pacific Ocean.

We now have to consider how much farther westward, out into the present Pacific, did the deposit extend; and also, when the uplift occurred, where was the original western margin of the uplifted land.

In the most western parts of the tablazo now remaining, there is nothing to suggest that any margin is being approached. Moreover, the deposit thickens westward, rather than thins.

From the general map of the tablazo (Folder IV.), we perceive at once how great has been the erosive power of the seas. At any rate, the cutting back of the Mancora Tablazo, performed by the succeeding Talara Sea, amounted to at least 10 miles for a long way down the coast. Further, those remnants of the Mancora Tablazo, which extend as far westward as the present coast, have suffered also the attacks of the Lobitos Sea, and of the present sea.

Hence, at first, we might infer that the Mancora

Tablazo must have stretched far westward beyond its present eroded edge. Examination of the ocean depths, however, renders that view untenable, for, even quite close to the coast, the bed of the present sea lies at great depth. From soundings on the Admiralty chart[1] we find that :

The 600-foot depth line is 5 miles from the coast.

The 6000-foot depth line is 15 miles from the coast.

The 12,000-foot depth line is 27 miles from the coast. (See map, Folder No. IV.)

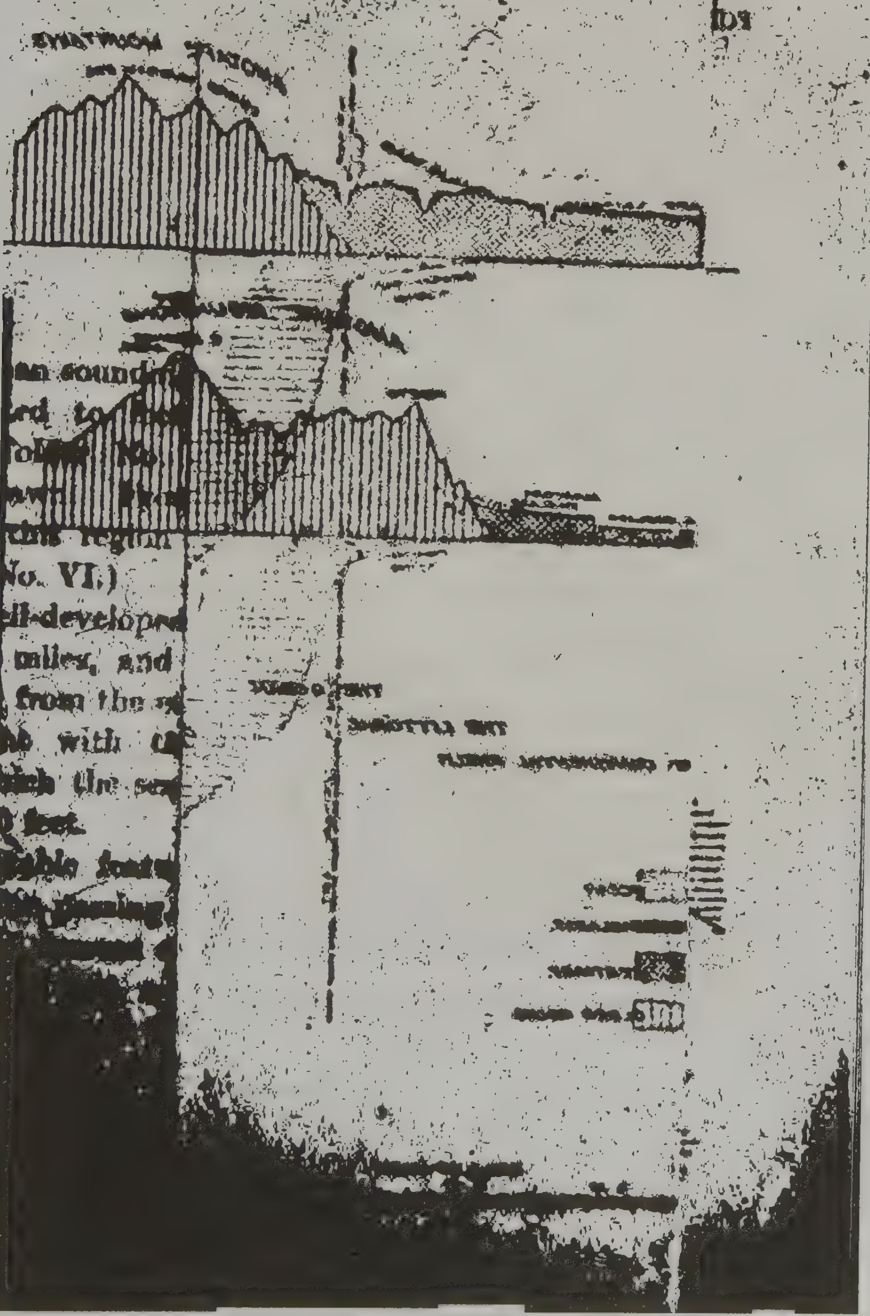
Thus it is most improbable that the uplifted Mancora Tablazo ever extended over this ground. Marine denudation and erosion to such a depth could hardly have occurred since the uplift of the deposit.

Consequently it is assumed that the western edge of the uplift was a line not far out from the present coast.

Further, it is thought that this deep sea existed prior to the Quaternary Period (see Chapter VII.), and that the west edge of the uplift coincided with the west margin of the comparatively shallow water. West of this, any representative of the Mancora Tablazo bed would be only deep sea oozes such as are now being formed.

Thus it is concluded that the western limit to the tablazo was a submarine line of faulting, not far from the present coast, at the edge of the continental shelf (see Chap. XIX., and Folder No. VI.) ; and this line was also an approximate limit to the shelly facies of the deposit.

[1] South America, West Coast, Sheet XVII.



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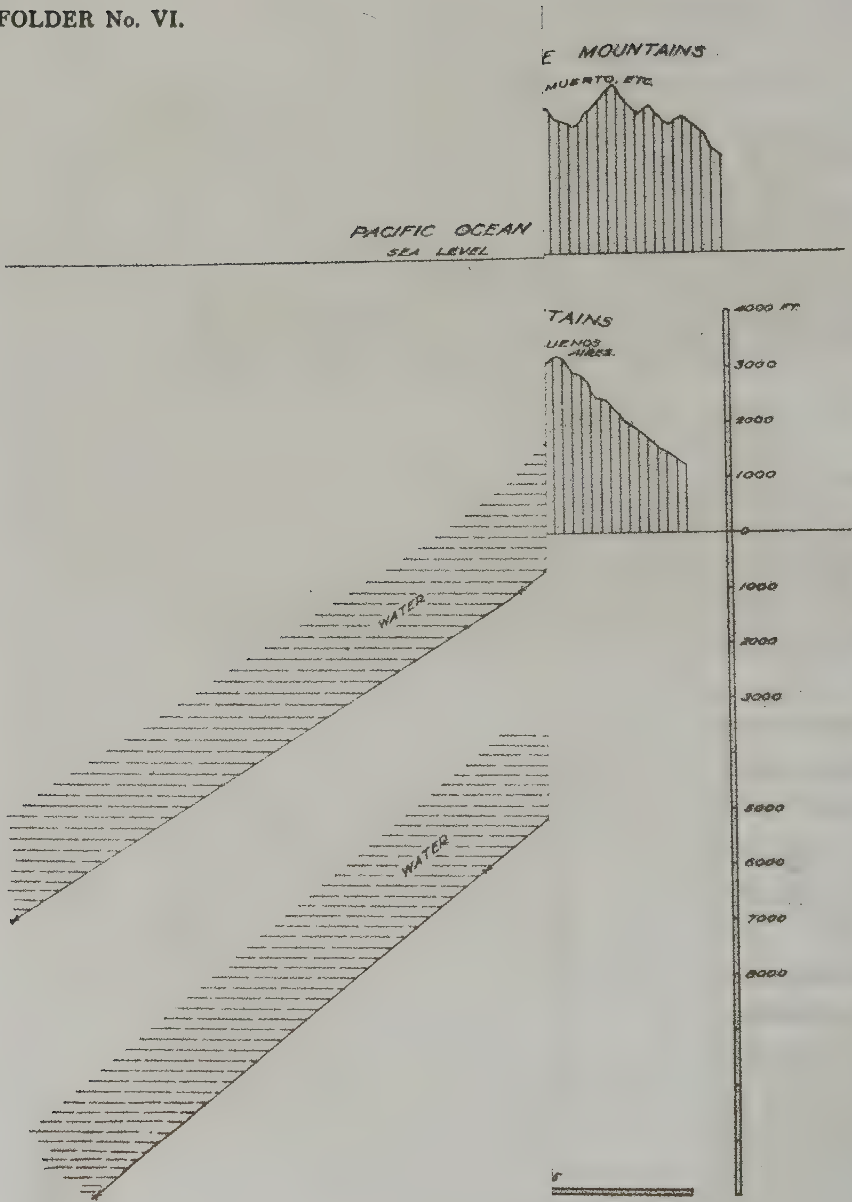

E MOUNTAINS
MUERTO, ETC.
PACIFIC OCEAN
SEA LEVEL
TAINS
UENOS AIRES.
WATER
WATER
4000 FT.
3000
2000
1000
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1000
2000
3000
5000
6000
7000
8000

CHAPTER XIX

THE PACIFIC FAULT

The ocean soundings shown on the Admiralty Chart[1] (converted to feet) have been transferred to the map (Folder No. IV.), and depth contours have been drawn. From these it appears that the sea-bed in this region has a characteristic form. (See Folder No. VI.)

A well-developed continental shelf, having a width of 4-20 miles, and an inclination of 1°-2°, extends outward from the coast. Its border is approximately coincident with the 600-foot depth contour, beyond which the sea-floor descends steeply to depths of 12,000 feet.

A notable feature of the shelf is its precipitous edge. For, passing over the edge of the shelf, there is an abrupt descent of some 2400 feet in about 1 mile. There is, in fact, a submarine cliff having a slope of 20°-25°. Beyond this the descent continues at about 5°, to a depth of 12,000 feet or more. The 12,000-foot depth contour lies within 30-40 miles of the shore.

The course of the submarine cliff, as deduced from the available soundings, does not follow the irregularities of the coast, but is more nearly a straight line. The land comes within 5 miles of this line, both

[1] South America, West Coast, Sheet XVII.

at Punta Parinas and at Cabo Blanco, the distance elsewhere varying according to the embayments of the coast. To northward and also to southward the distance of the land increases; but the evidence is less complete and is obscured by the deposits emanating from the mouths of rivers.

The straightness, the magnitude, and the steepness of this under-sea cliff, suggest that it is a great submarine fault-scarp, marking the main fracture at which that piece of earth's crust, known as the Littoral, has been lowered and raised repeatedly during the Quaternary Period. It is likely also that this fracture was a part, or possibly the main axis, of the great geo-fault which occurred after the close of the Tertiary deposition. (See Chapter VII.)

Thus this Pacific Fault Line, at the edge of the continental shelf, was the western boundary of the Tablazo deposits, and was the original western margin of the several uplifted Tablazos.

CHAPTER XX

THE POST-MANCORA UPLIFT

THE next event in the Quaternary Period was the uplift which raised the Mancora deposit up above sea-level, to form the tableland now known as the Mancora Tablazo. (See Folder No. V.)

Although its slope is not, to the eye, perceptible, the Mancora Tablazo is an inclined plane. First, there is an original gentle slope up, to eastwards, towards the shore-line of the deposit; and secondly, there is a slope down, from north to south, produced by the uplift movement.

The highest part of the tablazo is at the northern end, and thence proceeding from north to south, the surface falls 900 feet in 70 miles. Thus, for example, we find altitudes as follows:

At the northern end of the tablazo, three miles south of Quebrada Mancora	1000-1100 ft.
At Cabo Blanco	900-1000 ft.
Twenty miles south of Mancora, at Quebrada Collonitas	700 ft.
At Parinas, in Quebrada Salada, two miles south of Quebrada Parinas	450 ft.
At Quebrada Ancha	400 ft.
North of the Rio Chira, 6 miles north and 12 miles inland	320 ft.
South of the Rio Chira, at Arenal	250 ft.
At Payta	200 ft.

The surface of the Mancora Tablazo seems to be quite plane. It is not impossible, however, that when contours are drawn, some slight curvature may be revealed. (To northward, along the coast of Ecuador, there are several tablazos similar, or perhaps identical, with those of Peru. These were examined along the coast for 150 miles and were found to show many gentle undulations, some of which carried the beds below the present sea-level.)

The uplifting of the Mancora Tablazo was a gradual process, as is proved by the beach of Andean pebbles which composes its topmost layer. Evidently, as the bed emerged, the sea gradually withdrew westward, leaving a beach behind it.

The present elevation of the Mancora Tablazo is not, of course, due only to the Post-Mancora Uplift, but is the resultant of this and the several other lesser movements which have occurred since. But we can estimate the amount of the post-Mancora movement by subtracting the present elevation of the next lower tablazo (Talara Tablazo) which followed, and adding the amount of the subsidence movement which intervened. Because of the limited extent of the Talara Tablazo, this calculation is only applicable to that portion of the Mancora Tablazo which lies between Quebrada Parinas and the Rio Chira.

	Altitude Mancora Tablazo.	Post-Mancora Subsidence.	Altitude Talara Tablazo.	Amount First Uplift.
Mancora District .	1100	?	. .	? 800-900
Parinas and Talara District . . .	450	100	280	270
River Chira District	800	?	130	? 220
Payta District .	200	?	. .	? 150

Photograph kindly lent by Lobitos Oilfields Ltd

Fig. 35.—The Mancora Tablazo, and Quebrada Verde in the neighbourhood of Cabo Blanco.

This view shows the flat skyline made by the Tablazo, which here has an elevation of about 1000 feet.

Thus, approximately, the Post-Mancora Uplift amounted to about 900 feet near Mançora, decreasing southward to about 150 feet at Payta.

It is supposed that the western margin of the uplift was the Pacific Fault (see Chapter XIX.), along the edge of the continental shelf. If any movement occurred in the area west of this line, it probably was subsidence. It seems as though the strip of littoral lifts up like a trap-door, with its edges situated a few miles out in the Pacific and its hinge line in the Andes.

CHAPTER XXI

THE MANCORA BRECCIA FAN

Previous to the uplift of the Mancora Tablazo, the torrential rivers which occasionally swept down from the mountains, had flowed straight into the sea.

But now, when the next flood came, the rivers poured out on to a level plain. Here the velocity of the torrents was checked by the sudden change in grade, and the immense load of detritus which they had brought down had to be dropped. A great Breccia Fan or Cone, of extraordinary character, was thus formed at the mountain foot, and was spread far out over the Mancora Tablazo. (See also Part IV., p. 277.)

The deposit, which consists of angular stones—chiefly quartzite and slate—has a thickness of 100 feet or more near the mountains, decreasing gradually to 5 or 10 feet at a distance of 4 miles, and dying out in the farther distance. The surface is rather similar to the tablazos, though the stones on it are angular and there are no shells. (Figs. 36, 51, 52, 59, 110, 141.)

The greater part of this old Breccia Fan is beautifully preserved, though many canyons have been cut into it by later floods, and in places it is much dissected. The surface has a perceptible slope, which

Photograph by T. O. Bosworth.

FIG. 36.—General aspect of the Amotape Breccia Fan, looking north-eastward, 2 miles from the mountains.

The locality shown is 15 miles E.N.E. from Punta Parinas. The hills in the background belong to the Amotape Mountains. The right foreground shows the natural surface of the Breccia Fan. The left half of the view shows a small watercourse eroding into the deposit.

increases up to 2 or 3 degrees as the mountains are approached. Its conical form is still obvious to the eye.

Considered apart from the history of the tablazos, the whole deposit of breccia around the Amotape Mountains, formed at this time and during the succeeding episodes, is best named the Amotape Breccia Fan. But for present purposes, this oldest cone, which is the main body of the deposit, is referred to as the Mancora Breccia Fan—and the breccias added later receive corresponding names.

The subsequent history of the drainage is dealt with in Part IV.

SECTION C

THE TALARA EPISODE OF THE QUATERNARY PERIOD

CHAPTER XXII

SUBSIDENCE AND MARINE EROSION DURING DEPOSITION OF THE TALARA TABLAZO BEDS

While the Mancora Tablazo was being uplifted, the sea had gradually withdrawn westward. At length the movement ceased and the new sea—the Talara Sea — commenced its campaign of marine erosion against the new-formed land.

A subsidence movement now set in, and aided by this the sea made rapid progress, so that much of the Mancora Tablazo has been destroyed.

The character and position of the original new coast-line of the Talara Sea, at the commencement of this episode of subsidence and erosion, is matter for conjecture.

The most western parts of the Mancora Tablazo now preserved, were (then) 800-900 feet above the Talara sea-level, but as we have seen already, the uplift could not have continued many miles farther westward. Thus the new coast-line may have been a fault scarp hundreds of feet high. But more likely the edge of

the uplift consisted of a group of faults, near together, so that the fall from the land-level to the sea-level would not be quite abrupt.

At the conclusion of this episode, the plain of marine denudation reached nine miles inland from the present coast. Its eastern limit is now marked by a line of old sea-cliffs, with pebble-beaches at their foot, which is clearly preserved to this day. (See Chapter XXV.)

On this plain of marine erosion, the Talara Sea laid down a new deposit, which was afterwards upraised and now forms the Talara Tablazo.

This formation occupied 270 square miles of the present land, and also extended some distance out over the present sea. It is exposed to perfection, both as a surface and in sections, in the innumerable quebradas and ridges throughout the Talara area.

The plain is so smooth throughout that, although the tablazo deposit seldom is more than 15 feet thick, there are no islands of Tertiary rocks projecting up through it. Sometimes, however, scars of outcropping sandstone reach, or almost reach, the surface. These scars are bored with many circular holes, having diameter 1-1½ inches, which were, and sometimes still are, occupied by barnacle shells.

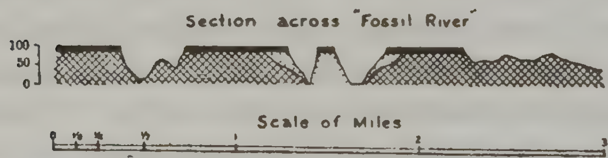
The evidence of the subsidence movement is of three kinds. First, we have the wide extent of the plane of erosion; secondly, we have the deposition of shell-limestone upon it; and thirdly, we have a peculiar river deposit (described in the following chapter), which proves a subsidence of at least 100 feet.

CHAPTER XXIII

THE "FOSSIL RIVER" OF THE TALARA TABLAZO

A PECULIAR development of the Talara Tablazo was found three miles north of Talara, where the deposit

FIG. 87.—Geological Map showing the "Fossil River" beneath the Talara Tablazos.



TABLAZO BED	*Plateau 270 feet above sea, formed by horizontal beds 5-10 feet thick, on plain of marine erosion.*
"FOSSIL RIVER"	*Deposit 100 feet deep, filling pre-Tablazo valley cut in Eocene rock. Passes up into Tablazo beds.*
TERTIARY ROCKS	*Shales and sandstones dipping 20° to N.W., exposed by denudation of Tablazo.*
SURFACE SAND	*Sloping down to sea, and occupying dry valleys.*

abruptly thickens out, from 10 feet, to 100 feet. The increase takes effect in the downward direction only,

and is due to the filling in of a deep trench. (See Fig. 37 and Fig. 38.)

This trench, which is 80-100 feet deep, is cut in the Tertiary rocks, the bottom of it being nearly 100 feet lower than the plain of marine erosion on which the Tablazo rests. It has a maximum width of one-half mile and is revealed for a distance of three miles. The north wall of the trench is steep and rough, but the south side, for a considerable distance, is formed by the dip-slope of some beds of Tertiary calcareous sandstone. The floor appears to be nearly flat, but just at the middle of the trench it is not exposed to view.

The extra thickness of the Quaternary deposits, required here to fill up the trench, is made up partly by increase in the shelly tablazo beds, but chiefly by the addition below of thick beds of gravel and Amotape stones. The strata vary greatly from place to place, especially in the transverse direction; so that no two sections are alike.

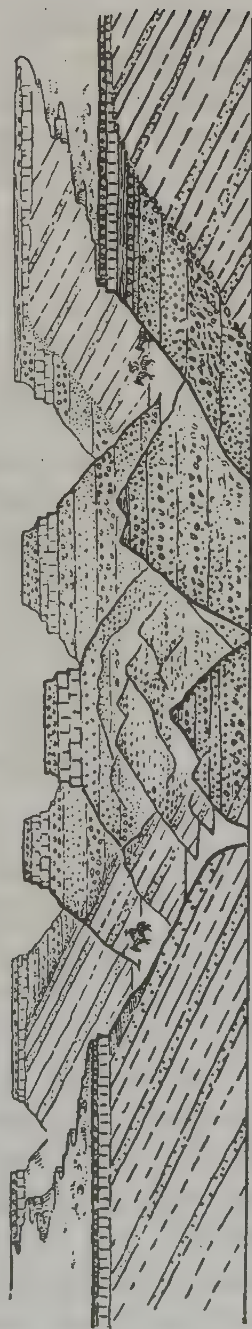


FIG. 38.—Generalised view of the "Fossil River," as seen looking westward along the course of this pre-Talara valley.

The following are two typical sections of the "Fossil River."

	Section A, 1¾ miles from coast, near north margin of deposit.		Section B, ¾-mile from coast, near north margin of deposit.	
Breccia Fan.			Amotape stones, up to 4", angular .	3 ft
Talara Tablazo and Fossil River	Pebbles (Andean), up to 5", with shells . . .	4 ft.	Pebbles (Andean) up to 4". . .	2 ft.
	Shell Rock . .	8 ft.	Shells : barnacles and pectens .	5 ft.
	Sandy Marl . .	6 ft.	Pebbles (Andean) .	1 ft.
	Stones (Amotape) worn, some Andean pebbles, also barnacles .	4 ft.	Shell-rock with some parts composed of barnacles, others of pectens, others of crescentic oysters. Some small pebbles . .	15 ft.
	Sand . . .	3 ft.	Stones (Amotape) worn . . .	10 ft.
	Stones (Amotape) worn, and bits of shells . . .	15 ft.	Calcareous Sand and some pebble seams . . .	15 ft.
	Marly brown sand	20 ft.	Stones (Amotape mainly), worn and subangular .	10 ft.
	Stones (Amotape), mainly 1" up to 8", worn, (with a few Andean and Tertiary) . .	25 ft.	Sand and stones .	15 ft.
	Sand, gravel, and some stones (Amotape) . .	20 ft.	Stones (Amotape), worn and subangular . .	10 ft.

The deposit is fully displayed; for it is intersected by deep quebradas, with many branches in all directions. It can be viewed very clearly from a hill, capped by tablazo, situated midway across the trench. The trench is plainly a pre-Talara "quebrada," and the deposit appears as the cast of a river —a fossil river—laid bare for inspection, with slices

and sections prepared in every direction. No unconformity is evident in the deposit; and there is a gradation up from the stone beds at the bottom, to the thirty feet of shell beds at the top. The uppermost tablazo seams are continuous across the infilled trench, and are totally unaffected by the presence of the trench and its contents, below.

This channel is cut to a depth exceeding 90 feet, and it is nearly filled with stones from the Amotape Mountains, which are not the stones normally abundant in the tablazo beds.

It cannot have been produced under the sea, but must be the work of a river. Further, as the deposit is covered by the ordinary shell-limestone of the Talara Sea, a subsidence of more than 100 feet must first have occurred before the Talara Sea passed over it.

(No other "Fossil Rivers" were observed.)

CHAPTER XXIV

EXTENT OF THE TALARA TABLAZO

The Talara Tablazo, as seen to-day, is a plateau 25 miles in length and having a width of 4-6 miles. The main spread of it stretches from the Parinas Valley (lat. +10), in the north, to the Chira Valley (lat. −12) in the south. Farther northward, some remnants of the tablazo are found as far as Lobitos, and perhaps also at Point Restin (lat. 25). (See map, Folder No. IV.)

The eastern boundary is an old shore-line of the Talara Sea, and is for many miles wonderfully preserved, as a line of raised sea-cliff, eight to ten miles inland, and parallel to the present coast.

The western margin is a very ragged edge, due to erosion of the plateau by later seas, assisted by some subaerial denudation. Thus in the Talara district the tablazo reaches to the present sea, and caps the modern cliffs; but farther south, the edge of the tablazo has been eroded back inland a distance of from two to seven miles.

It is clear that the whole of the ground west of the old cliff, formerly was covered by the deposit. No part of it rises above tablazo level, and many hills retain a small cover of tablazo remains.

The area of the present land, which was formerly

overlain by the Talara Tablazo, is about 270 square miles, of which some 120 square miles are still completely covered.

Originally, no doubt, the Talara Tablazo continued along the coast, both north and south of the present remnant. The region to southward has not been examined; but 40 miles northward of the tablazo as outlined above, and beyond our map, there are some important raised floors occurring north of the Quebrada Mancora and extending thence as far as the valley of the Rio Tumbes. As regards altitude, these accord fairly well with the Talara Tablazo. Still farther north, in Ecuador, there are several tablazos having altitudes less than 300 feet. Probably one of these is a continuation of the Talara Tablazo.

CHAPTER XXV

THE RAISED SEA-CLIFF OF THE TALARA SEA

THE old sea-cliff of the Talara Sea is well preserved throughout almost the whole length of the tablazo, from the Parinas Valley to the Chira Valley. It is one of the principal topographic features of this part of the country. Where intact, the cliff has a height

FIG. 39.—Sketch of the raised sea-cliff and beaches of the "Talara Sea," 12 miles inland.
Base of the cliff at 380 feet above level of present sea.

of 100-120 feet, with its base 250-400 feet above the sea. The head of the cliff is the present western edge of the Mancora Tablazo, and the foot of it is the eastern limit of the Talara Tablazo. (Near the middle of our map the Talara Tablazo has an altitude of about 270 feet, whilst that of the Mancora Tablazo is, say, 400 feet.) (See Figs. 39, 40, and 41.)

The cliff is situated eight or nine miles inland, trending parallel with the present coast. The old shore-line was fairly smooth, with an important promontory (lat. $2\frac{1}{2}$, long. $10\frac{1}{2}$), just south of Quebrada Ancha. There are several original gaps in the line of cliffs, where watercourses broke through them. The widest of these is the gap of the Quebrada Ancha, which was then the mouth of a river entering the Talara Sea.

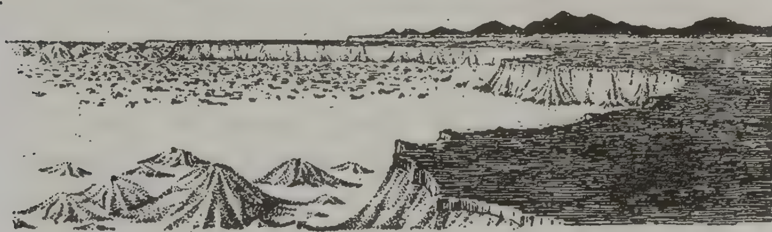


FIG. 40.—Sketch showing the Talara and Mancora Tablazos, viewed from a point on the Talara Tablazo (about lat. – 9, long. 15) 9 miles south-west of the mountains, looking towards them.

In the far distance, but in front of the mountains, is seen the old cliff of the Talara Sea (appearing in this picture as a white line), beyond which (though not discernible) lie the Mancora Tablazo, the Breccia Fan, and the Amotape Mountains

In the right foreground is the surface of the Talara Tablazo, having here an altitude of about 140 feet, and an eroded edge.

In the extreme left background is the surface of the Salina.

The low sandy ground in the centre (shown white in this sketch) has been formed by erosion of the Talara Tablazo.

The cliffs of the Talara Sea have just the same form as the sea-cliffs of the present time. They are steep and to some extent fretted. The top is horizontal because it is formed by the horizontal limestone of the Mancora Tablazo.

From the edge of these old cliffs the observer looks down on to the bare desert plain of the Talara Tablazo, and sees it stretching away into the far distance and terminating in a horizontal straight line against a background of sky. At night, or in a dim

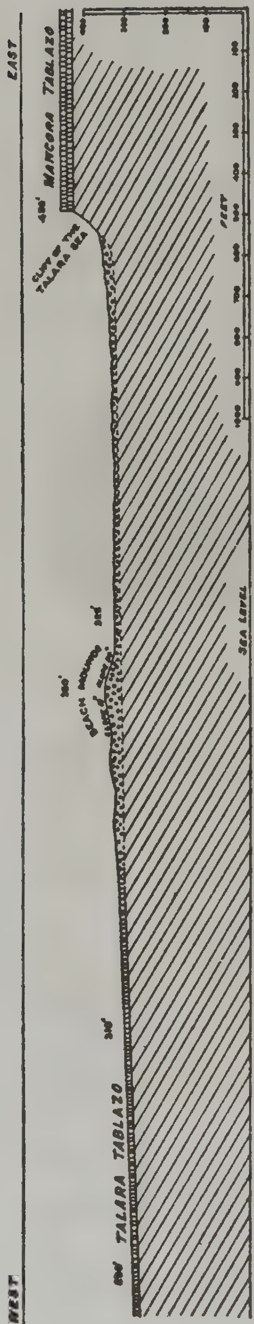


FIG. 41.—Section showing the old sea-cliff of the Talara Sea and the Beach-mounds, about 12 miles inland from Punta Parinas.

This low bank or chain of banks is about 20 feet high, and forms a conspicuous feature with a characteristic shape of its own, as shown in the accompanying section. (Fig. 41.)

The stones are much worn, and show to perfection the rounded and flattened shape of beach pebbles. The pebbles here are much larger than those of the normal Tablazo deposit, some of them exceeding 12 inches across. All three classes of pebbles (see Chapter XIV.) are present in the beach mounds.

The Andean pebbles here have been derived partly from the Mancora Tablazo which caps the cliff, also no doubt partly from the same original southern source which supplied Andean pebbles to the Mancora Sea.

The Tertiary pebbles are present here in unusually large quantity. Their source is evident; for large block-faulted masses of particularly pebbly Tertiary rocks were exposed at the mouth of the Ancha, forming the large promontory already mentioned, which might be called Punta Ancha. The same rocks are exposed, also, in the cliffs, underneath the Mancora deposit. Thus the Ancha River, and also the marine erosion, would contribute this material to the beach.

The Amotape stones are rounded and smoothed much more than usual. These are not very numerous. Doubtless they were introduced by the Ancha River from the mountains, which are only about 7 miles distant. There are also some blocks of these rocks a foot or two in length.

Some broken shells are mixed up with the stones in the pebble banks.

In some places where the cliff is not fully preserved, there is an appearance of intermediate steps and slopes, down from the Parinas Tablazo to the Talara Tablazo. These are due partly to differential erosion of the horizontal beds, and partly to slips.

CHAPTER XXVI

CHARACTER OF THE TALARA TABLAZO DEPOSIT

THE Talara Tablazo is but a slight deposit to have covered so considerable an area.

The normal tablazo consists almost wholly of shelly pebble-beds and massive pebbly shell-limestone.

The thickness is greatest in the north and least in the south, decreasing from about 20 feet down to 8 feet. The change is not uniform, and there are some places where the thickness is above or below these limits. In particular, there is the important increase at the site of the "Fossil River" already described (Chapter XVI.).

At the southern end of the tablazo the deposit thins out, and consists principally of some 5 feet of pebbles, underlying a foot or two of shell-limestone which is more or less disintegrated by solution.

The Pebbles and Pebble-beds.—The pebbles are indistinguishable from those of the Mancora Tablazo. They have been intensely smoothed and worn to the regular shape of beach pebbles. Most of them are 2-4 inches in diameter, and generally the largest do not exceed 5 inches. (See Fig. 31.)

The pebbles belong mainly to the Andean class, though generally these are accompanied by some of

those derived from the Tertiary. Amotape pebbles are present abundantly in some parts of the tablazo, notably in the district of the "Fossil River." They occur in special seams, with or without any Andean pebbles.

A bed of Andean pebbles almost invariably forms the upper part of the deposit. In places the thickness of this bed is as much as 10 feet, though more often it is 2 or 3 feet and sometimes less than 1 foot. With the pebbles are mixed some sand and shells. The shells may be few or many. In some parts great oysters, 18 inches or more in diameter, are abundant amongst the pebbles; and in many other places there is a quantity of large, strong pectens. A seam of pebbles is commonly found at the base of the tablazo, but it is not nearly so constant or so prominent as the bed that forms the top. This basal bed often is composed largely of Amotape stones.

The Shells and the Shell-limestone.—The shells of the Talara Tablazo are practically identical with those of the Mancora Tablazo. (A list of them is given in Chapter XV.)

The shell-limestone is similar to that in the Mancora Tablazo. Sometimes it is a massive rock, but often it is an aggregate of shells, loosely held together by a calcareous matrix of broken shells and sand.

In some parts the lime rock is largely made of chalky *Glycimeris* and *Chione*. In other places there is a remarkable abundance of the large, strong *Pectens*, preserved in a hard, clean material and loosely cemented in amongst the stones. Yet again, there may be a profusion of great oysters 1 foot or 18 inches in

Photograph by T. O. Bosworth

FIG. 42.—A vertical section of the Talara Tablazo Bed, here composed mainly of Barnacles, capping an inland cliff about 8 miles N.E. from Punta Parinas.

Here the uppermost 3 feet of the deposit are seen. The top part of it as usual consists of Andean beach-pebbles. Below this follows a pebble-shell-limestone, composed, at this locality, of Barnacles and Andean Pebbles. (The length of the scale seen on the picture, is 6 inches.)

diameter; and sometimes there is a preponderance of *Thais* and *Oliva*, or of large *Turritellas* 6-8 inches in length. But the commonest fossil in the limestone is the barnacle; and frequently the rock is almost wholly a mass of these barnacles and groups of barnacles, almost perfectly preserved. (See Fig. 42.) Many of them are 4, 5, or 6 inches in length, and 1 or 2 inches in diameter. They still infest the sea to-day, and are cast up in quantities on the beach.

In many places the flood rains have penetrated through the pebble bed at the top of the tablazo, and into the shell-limestone. Afterwards, by surface evaporation and capillary action, the water has been drawn up again into the pebble bed; and there the lime has been deposited. These lumps of lime, thus formed, are used by the natives for plaster, whitening, etc.

TYPICAL SECTION OF THE TALARA TABLAZO BED

(1¾ miles S.E. of Talara)

10 feet—Pebble-shell bed.
Andean beach pebbles.
Pectens, barnacles, crescentic oysters, etc.

3 feet—Decomposed limestone.
White calcareous residue.
Shells and some stones.

1 foot—Basal bed.
Stones, calcareous matter, some large blocks of local sandstone bored by barnacles.
Masses of corallite.

ANOTHER SECTION OF THE TALARA TABLAZO BED

(Within ½ mile of preceding section)

13 feet—Pebble bed.
Andean beach pebbles and shells.

7 feet—Shell-limestone, with stones at base.

CHAPTER XXVII

THE TALARA TABLAZO SURFACE

The surface of this tablazo has the same appearance as the Mancora Tablazo. (See Figs. 43, 44, 45.)

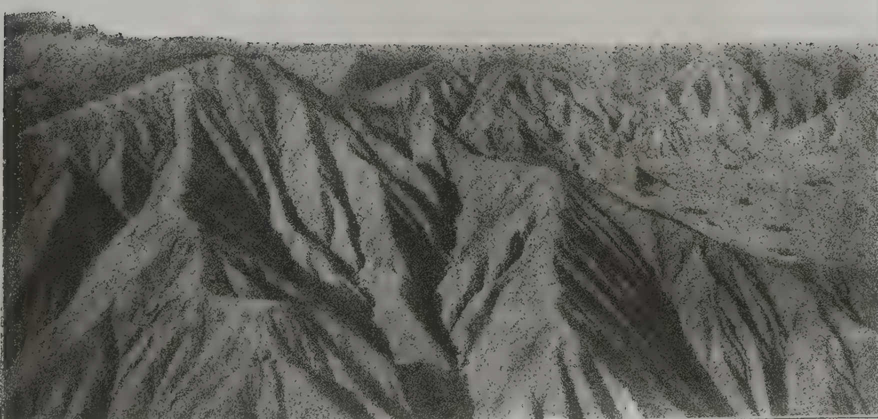
The traveller who comes up to this plateau from the west meets with a surprising change in the country's aspect. Approaching from the sea, he has traversed the coastal dunes and the salt marshes (salinas), and then has passed over sharp ridges and intricately fretted bad-lands, swept by blown sand, and now he has ascended, by way of some winding steep gully, to an elevation of about 250 feet. At once a breeze of cooler air meets him and he emerges on to the edge of the tablazo. Before the eye, stretches a very level plain, smooth as a gravel court, though strewn with pebbles and shells, and bare except for an occasional stunted shrub and some small sand dunes.

In reality this plain is trenched by innumerable canyons or quebradas, but so steep and narrow are they that the glance passes across them without notice, except when very near. To seaward, far and near, are many remnants of the tablazo, capping flat ridges and isolated hills. All these are exactly on the level of this plain, and, by the eye, they are accepted immediately as a part of it.

Photograph by T. O. Bosworth

FIG. 43.—Talara Tablazo, dissected by a Quebrada, 1½ mile S.E. from Talara. (Lat. 5, long. 4.)

Altitude of Tablazo here is 280 feet



Photograph by T. O. Bosworth

FIG. 44.—Dissection of Talara Tablazo, in the Talara district.

FIG. 45. b (abou

Inland, far in the distance eastward, is the old cliff-line of the Talara Sea, level-topped and resembling a wall. Beyond that, in the blue distance, if the sand-storm does not obscure the view, rise the ragged peaks of the Amotape Mountains. (See Fig. 40.)

The pebbles on the tablazo surface have been much broken up, by the sun's heat, into fragments; and they have then been carved and polished by the drifting sand. Most of them have a shiny black appearance. The greater part of the tablazo is, however, overlain by a thin fan of angular Amotape stones. These are further broken by the sun, and have seasoned to a rusty-brown colour.

At its inland edge, the tablazo slopes upward perceptibly toward the former sea-cliff; and the old beaches, remaining as ridges and mounds of larger pebbles, interrupt the evenness of the surface.

CHAPTER XXVIII

THE ORIGINAL WESTERN LIMIT OF THE TALARA TABLAZO

THERE is no means to determine how far the Talara Tablazo originally extended over the site of the present sea. As in the case of the Mancora Tablazo, it is deduced that the deposit in its shelly form could not have continued many miles from the present coast, because of the sharp descent of the ocean floor to abysmal depth. It is thought that the original western edge of the uplifted Talara Tablazo was the same great submarine fault-line—the Pacific Fault, (see Chapter XIX.)—along the edge of the continental shelf, which originally bounded the Mancora Tablazo.

CHAPTER XXIX

THE POST-TALARA UPLIFT

THE uplifted Talara Tablazo is a smooth plain, slightly inclined. First there is an original slope of the deposit upwards towards its shore; and secondly there is a downward slope of 10 feet per mile, from north to south, caused by the movement.

Thus in the district of Talara the altitude of the tablazo, where it caps the present sea-cliff, is 280 feet.

At the inland margin, south of the Quebrada Ancha, the altitude attains to 340 feet.[1]

At its south-west end, towards the Chira valley, the tablazo has an elevation of only 120 feet.

The uplift movement probably was a gradual process. It is thought that the layer of beach pebbles at the top of the tablazo was the marginal deposit of the retiring sea. The pebble banks which occur at intervals near the eastern border of the tablazo, presumably mark brief pauses in the recession of the sea.

To estimate the total amount of this uplift movement, we must subtract the elevation of the succeeding Lobitos Tablazo from the present elevation of the Talara Tablazo. (In this case the intervening subsidence movement is being ignored,

[1] Measurements only approximate.

as we have no evidence that it amounted to anything considerable.)

	Altitude of Talara Tablazo.	Altitude of Lobitos Tablazo (inner edge).	Amount of Post-Talara Uplift.
North part of Talara Tablazo, near Talara . . .	280	100	180
South part of Talara Tablazo, 8 miles from Rio Chira . .	135	80	55

Out to seaward, the boundary of the uplift movement probably was the same great fracture line—the Pacific Fault (see Chapter XIX.)—as in the case of the Mancora Uplift.

CHAPTER XXX

THE TALARA BRECCIA FAN

After the Talara Tablazo was raised above the sea, breccia fans were deposited on the new land in the same manner as they were deposited on the Mancora Tablazo. In this case, however, the deposit is much smaller because of the greater distance from the mountains.

Several rivers entered that part of the Talara Sea of which we have knowledge, and in the case of the Ancha and also some of the smaller streams, the gaps in the old sea-cliff through which they entered are still plainly seen. At the mouth of the streams alluvial fans were produced, which unite to form the spread of Amotape stones and gravel which covers the greater part of the Talara Tablazo.

The deposit is from ten to fifteen feet thick near the source,—fading away to a foot or less in a distance of six miles. It consists of angular stones—quartzite, slate, spotted slate, and occasional pieces of granite. They are of all sizes up to, say, a foot in length, becoming smaller with increase of distance. The bulk of the material is of stones one, two, or three inches across, with finer interstitial gravel. On the surface of the tablazo these stones are broken up by the sun's heat into smaller pieces. (See Part IV.)

SECTION D

THE LOBITOS EPISODE OF THE QUATERNARY PERIOD

CHAPTER XXXI

SUBSIDENCE AND MARINE EROSION DURING DEPOSITION OF THE LOBITOS TABLAZO BEDS

After the uplift of the Talara Tablazo it appears that subsidence again set in, though in this case the movement was small and did not continue long.

Only small portions of the new tablazo are preserved, and we have but little data concerning the plain of marine erosion produced.

The initial coast-line of the Lobitos sea would be the original western edge of the Talara Tablazo, which was along the fault line, out in the present Pacific, as already discussed.

The final coast-line, when the Lobitos marine transgression ceased, was, of course, the present inland limit of the Lobitos Tablazo. It is marked by an old line of sea-cliffs, of which a number of small parts are still intact. (See Fig. 46.)

The total width of the plain of erosion cannot be determined, but the maximum distance of the old cliff inland from the present coast is 4 miles. (See map, Folder No. IV.)

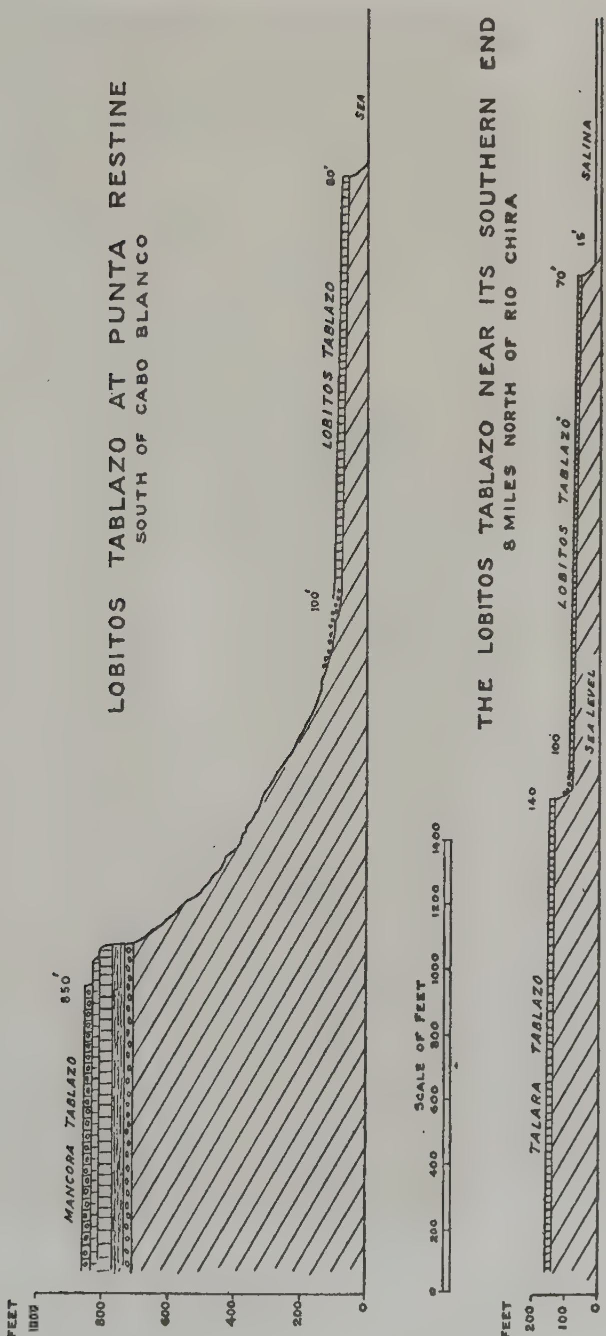


FIG. 46.—Sections across the Lobitos Tablazo.

CHAPTER XXXII

EXTENT OF THE LOBITOS TABLAZO

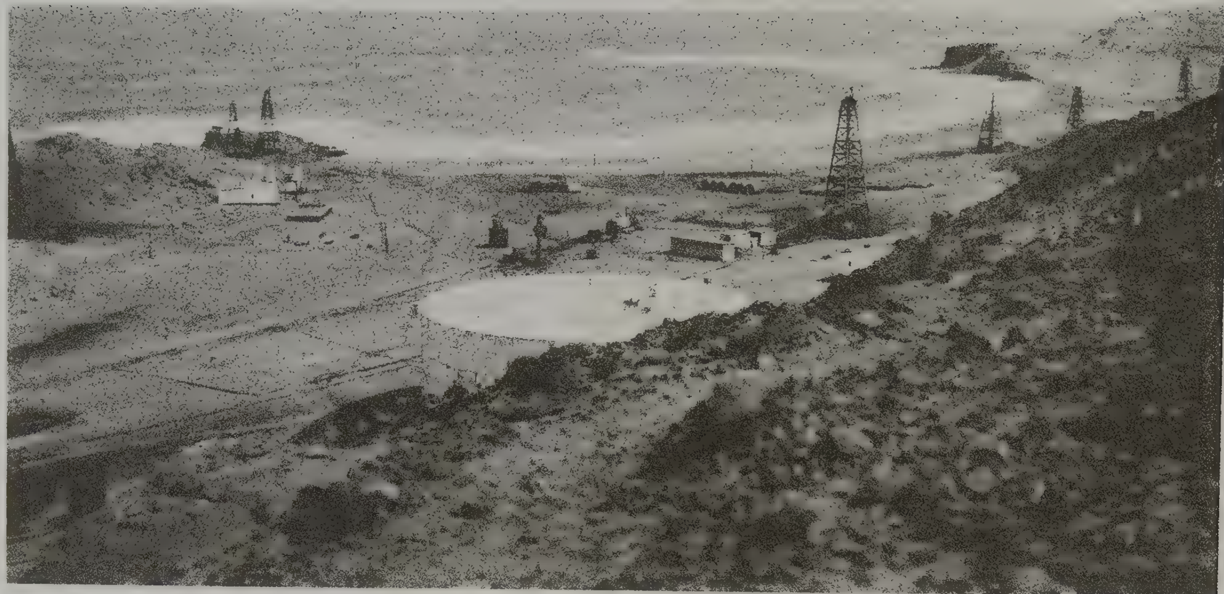
THE Lobitos Tablazo has suffered greatly from denudation by wind and wave. Presumably it was once represented by a continuous strip of plateau extending along the whole coast of our map; but most of it has now been destroyed. Those parts which are still intact do not exceed a few hundred yards in width. (Figs. 46, 47, 48.)

The fragments of the Lobitos Tablazo are found more or less continuously as far north as Mancora, and farther north, beyond our special area, this tablazo is almost certainly represented amongst the group of raised beaches which occur along the coast between Mancora and Tumbes. In Ecuador, also, there is a well-developed tablazo which is probably a farther continuation.

To southward the remnants of this tablazo are found to within 5 miles of the Rio Chira.

The largest piece of the tablazo preserved is a strip 7 miles long, with width varying up to a quarter of a mile. This strip is a conspicuous feature in the topography, on the inland side of the Salina plain, about midway between Punta Parinas and the Rio Chira. Its eroded edge stands up on the desert plains like a vertical well, some 40 feet high, situated 2 miles inland and trending parallel with the coast.

From the Chira southward, as far as Payta, the Lobitos Tablazo has been entirely destroyed by the advance of the present sea.



Photograph kindly lent by Lobitos Oilfields Ltd.

FIG. 47.—The Lobitos Tablazo, north of Lobitos.

The Tablazo, having here an elevation of about 80 feet, is seen capping the cliffs, immediately beyond the distant derricks. This view was taken at the north end of the main Lobitos Oilfield, between Lobitos and Restin. In the farther distance the cliffs of Cabo Blanco are faintly seen, and the skyline is formed by the surface of the Mancora Tablazo, which has an altitude of 900 to 1000 feet.

Photograph kindly lent by Mr. Beeby Thompson.

FIG. 18.—The Lobitos Tablazo at Punta Restin.

A small remnant of this Tablazo, which has an elevation of about 80 feet, is well seen in the left half of the picture, capping the foremost line of cliff. The tanks stand upon it. The Tertiary rocks here belong to the Negritos Formation—in the distance they are overlaid by the Mancora Tablazo bed.

CHAPTER XXXIII

THE RAISED SEA-CLIFF OF THE LOBITOS SEA

Much of the shore-line of the Lobitos Tablazo is easily traced. It is generally within a mile of the present sea, and its maximum distance inland is about 4 miles. Near Lobitos the foot of the old sea-cliff is 100-110 feet above present sea-level.

The old cliff is particularly well seen in the Lobitos neighbourhood. Here parts of it are perfectly preserved, and beach mounds and shell banks are heaped up on the Lobitos Tablazo at its foot.

Passing south of Punta Capullana (lat. 12), across the mouth of Quebrada Parinas, the evidence, for a distance of 2 miles, has been obliterated by river denudation. But at Punta Malaca (lat. 9), and in its vicinity, portions of the tablazo and its old cliff are again seen.

South of Talara the old coast was somewhere out in the present sea, and the tablazo has been entirely destroyed; but near Punta Parinas it came inland again. This district is greatly denuded, but the line of beach deposits preserved is 2 or 3 miles inland.

Continuing south-eastward, there are now wide plains at sea-level (Salinas), which extend several miles inland. It is here that the Rio Ancha entered

the Lobitos Sea; and there may have been a long embayment of the coast. No cliff was identified here.

Eight miles south-west of Punta Parinas the deposit is found capping a long narrow ridge 2 miles from the coast. This remnant extends for 7 miles, and terminates against higher ground bearing the Talara Tablazo, where the cliff is again well seen.

CHAPTER XXXIV

CHARACTER OF THE LOBITOS TABLAZO DEPOSIT

The Surface of the Tablazo.—In those places where the tablazo is well preserved, the surface is a smooth plane, sloping up at a perceptible angle towards the ancient beach and cliff. The surface is strewn with a profusion of shells, and also with stones. The shells are better preserved than in the other tablazos, and many would hardly be distinguished from shells that had lain long on the present sea-shore. There are many small and delicate shells, not noticed on the other tablazos; but nearly all of the former species also are found. (The reason for this is discussed in Chapter XV., where also a list of species will be seen.)

The pebbles belong to all the three groups before mentioned, and are of the perfect beach-pebble shape.

The Deposit.—A few miles north of Lobitos, at Punta Monte (lat. 18), the deposit consists of four feet of stones, underlain by one foot of limestone. The stones are pebbles of quartz-schist, etc., derived from the Tertiary. The surface is strewn abundantly with shells.

Here, in a distance of half a mile, on approaching the old cliff the deposit thickened to twelve feet:

4 feet—Pebble band,
4 feet—Pebble-limestone with shell fragments,
4 feet—Stones and blocks of local rock.

Near Lobitos, the deposit consists of five feet of shell rock, thickening in two or three hundred yards, as the old cliff is approached. At the foot of the cliff is a pebble bank containing pebbles of all the several kinds, many of them measuring up to 6 inches across.

The fragments of tablazo, $1\frac{3}{4}$ miles south of Punta Malaca, consist of five to six feet of massive rock, which breaks into large blocks. This rock is almost wholly composed of shell fragments, and contains but few stones.

In the district of Punta Parinas there are parts of this tablazo preserved somewhat farther inland. These are mainly pebble beaches, formed along the old shore-line, on retreat of the sea. They are five to ten feet thick, and consist of Andean pebbles. *Pectens* and occasionally other shells are found along with the stones.

The "Seven Mile" strip of this tablazo, in the south (lat. -5 to lat. -10), is about ten feet thick, and is variable in character. A section towards the southern end showed :

3 feet—Pebbles and some shells.
3 feet—Pebbles and sand and shells.
4 feet—Sand and pebbles and seams of pebbles.
$\frac{1}{2}$ foot—Brown sand with bits of shells.

The pebbles here are Andean, perhaps with some Tertiary, and measure up to four inches. The shells are mainly barnacles, and also a very fragile, pearly oyster, which is common on the present shore.

CHAPTER XXXV

THE POST-LOBITOS UPLIFT

The uplift movements which have raised the Lobitos Tablazo, amounted to about 100-120 feet.

Much of the tablazo is only about 60 feet above sea-level, but the surface generally slopes up toward the old shore-line at an angle of two or three degrees; and along the foot of the old cliff, the beaches stand at an altitude of 100-130 feet, decreasing from north to south.

This gives us the approximate uplift, though, to be more exact, we should have to add and subtract small amounts due to some lesser movements which have since occurred.

SECTION E

THE SALINA EPISODE OF THE QUATERNARY PERIOD

CHAPTER XXXVI

SUBSIDENCE AND MARINE EROSION DURING DEPOSITION IN THE SALINA PLAINS

THE Salinas are plains recently abandoned by the sea, forming a strip of territory between the Lobitos Tablazo and the present shore. Eventually they will be the eastern portion of a new tablazo. (Folders VII. and VIII.)

After the uplift of the Lobitos Tablazo, subsidence was again resumed and the sea again advanced, destroying almost the whole of the tableland last raised, and leaving only the remnants, which have been described in the foregoing Chapter XXIV.

The actual plain of marine erosion, carved out upon the solid rocks during this subsidence, is not exposed to view. And only small portions of the marine deposits, which are being laid over it, have yet emerged from the sea. These are seen as smooth plains or "salinas," bordering the coast; which are a

conspicuous element in the desert geography (Fig. 49). The Salina plains extend inland two or three miles, but the full extent of the plain of erosion is not known because of the uncertainty as to how far west it started.

CHAPTER XXXVII

EXTENT OF THE SALINA PLAINS

The Salina plains are found along the western border of our map, from one end to the other. They are not perfectly continuous, but are interrupted here and there by places where the previously uplifted land is still being attacked by the sea.

The Salina plains occupy 75 square miles of the area here specially considered, the greater part being one large continuous area, extending from Punta Parinas to Colan (lat. 0 to lat. –23).

The inland limit, as in the case of the tablazos, is an abandoned sea-cliff. Throughout many miles this sea-cliff is entire, but in the southern part of the map, erosion by floods, and especially by blown sand, has cut back the cliffs and enlarged the plain. The original plain probably nowhere reached more than four miles inland from the present sea.

Photograph by T. O. Bosworth.

FIG. 49.—On the Salina Plain, a few miles S.E. from Punta Pariñas.

Mirages in the distance give the appearance of water and hills along the skyline. All the apparent water and all the hills, except the hill on the extreme left, are entirely due to mirage

Photograph by T. O. Bosworth.

FIG. 50.—New land, bordering the sea south of Tumbes, near the landing-place of Pizarro.

Due to the uplifting movement now in progress, this ground has been abandoned by the sea during geologically recent time. The view is taken looking down on the plain, in a northerly direction, from a place on the land above the abandoned sea-cliff. The sea occupies the left distance. The linear arrangement of the vegetation is parallel with the present shore-line.

CHAPTER XXXVIII

THE SALINA PLAINS—THEIR CHARACTER, SURFACE, AND ABANDONED SEA-CLIFFS

The Salina plains rise from sea-level (highest spring tide), to 10 or 15 feet above it, at their inland edge. (Folders VII. and VIII.)

The most important salinas are those in the southern half of our map; but those north of our special area, between Mancora and Tumbes, also present some interesting features. We will briefly trace them from north to south.

South of Tumbes (lat. 76), the sea-cliff is now 2 miles inland: it is continuous south-westward for about 12 miles, as far as Malpaso, near Zorritos (lat. 71), where it meets the sea.

The strip of territory here abandoned by the sea, is a smooth sandy plain, with shells and stones lying upon it, and with regular pebble beaches along the foot of the old sea-cliffs. There is some vegetation on the plain, including algarroba trees and many tree-cacti (*Cardo*) (Fig. 50). The plain has certainly been dry for a long period. It was here that the Spaniards, led by Pizarro, made their first landing in Peru. "Inca" remains are found on the plain, and it was seen that some of the land had once been irrigated

to within a few hundred yards of the present high-water line. The irrigation trenches had been fed by a raised, stone-lined canal from the Rio Tumbes.

After passing Zorritos, we find the cliff again receding some distance inland; and thus it continues as far as Mancora (lat. 41), returning only occasionally to the sea.

From Mancora south-westward for 34 miles, some coast-erosion is still active, and the cliffs are still being cut back in many places by the waves. But after passing Cabo Blanco and Lobitos we again find ground abandoned by the sea; notably the wide plain at the mouth of the Parinas Valley (lat. 11).

Around Talara (lat. 6) the old cliff curves inland, bounding what was once a large bay but is now a sandy plain, measuring about 1½ miles across from north to south and 1½ miles from east to west. This plain is surrounded on three sides by steep cliffs, 200-280 feet high. On ascending them we arrive upon the Talara Tablazo. The cliffs are unbroken, though they are now fretted in the manner of badlands.

The inner part of the plain is occupied by blown sand, but the part near the sea is strewn with shells and stones. In drilling a hole near the sea, fifty feet of soft sands was penetrated before any solid strata were met.

The village of Talara is now on land which, previous to this latest uplift, was more than a mile out to sea: the Talara Beacon and rocks were then an island.

During the last wet period (1891) the flood-water swept down over most of the old bay, and Talara was again an island, to which provisions had to be sent by boat.

Continuing southward from Talara there is another Mal Paso, where the waves are now working against cliffs 280 feet high; but approaching Punta Parinas (lat. 0) there is an old bay one-half mile wide, which is now dry. The village of Negritos is built along the old sea-cliff. Punta Parinas, Punta Balcones, and the Brown Hills were a group of islands at that time.

Passing round Parinas Point we come to one of the most interesting parts of the new land. From this point to the River Chira, and thence to Colan (lat. -23),—a distance of 30 miles,—the coast is lined by a belt of sand and shell-dunes, in the form of continuous ridges, parallel to the coast, and some thirty feet high. The width of the dune belt is from ½ to 1½ miles.

On the landward side of these dunes, is a plain of irregular shape, known as the Salinas. This ground has been much swept by wind and by flood-water, so that the old sea-cliff is recognisable only in places; and the plain has been somewhat enlarged by the erosion. The plain is from -1 to +15 feet above the sea-level (spring tide).

At high spring tides the sea enters on the north side of Parinas Point, where it has established a regular channel, and spreads a sheet of water over part of the Salinas. When the tide subsides the water

on the plain remains, and in the course of two days it evaporates, leaving the Salina covered with a deposit of white salt (Fig. 78) (the details of the matter are described in Part IV.). After this, blown sand covers the salt, and during further desiccation there is a growth of selenite crystals in the crust of sand and salt. This crust is dangerous to ride upon, for beneath it there is a mixture of sand and water, into which a beast will sink.

At the present day, from one to two square miles of Salina is thus covered by the water, to a depth of a few inches; and the sea comes as far as one mile inland. A farther area is more or less saturated with the sea water, and at any place salt water can be obtained on digging a hole.

The more inland parts of the Salinas, in their day, have similarly been subject to these incursions of the tide, though they are now beyond its reach.

In the older parts of the Salinas, the material nearest the surface has to some extent been disturbed and rearranged by wind and water. Parts now are strewn with sea-shells, and also some stones, which generally are broken by the sun, and are wind-cut.

There are no sections revealing the Salina deposit, but borings at its seaward edge, about one or two miles from its old coast, show 50-100 feet of sand and shells.

The upper part of the deposit doubtless was laid down during the retreat of the sea, but it is difficult to say how much of the deposit was formed during the advance.

The tablazo which bears most resemblance to the Salinas, is that which occurs half-way between Mancora

and Tumbes. It is a raised beach, 150 feet high and 30 feet thick, consisting of brown sand with shells.

It is not known if there is any material in the Salina deposit at all resembling the thick limestones of the Mancora Tablazo.

CHAPTER XXXIX

THE PRESENT UPLIFT

An uplift movement is at the present time in progress, which is causing the retirement of the sea from the Salina plains above described. The movement has not yet amounted to more than 10-15 feet at most, although its effects are so conspicuous.

The time that already has been occupied in this comparatively small uplift probably is many thousands of years. Occasionally there are small earthquakes, one of which ruined part of the town of Piura (lat. – 38, long. 49) in 1912; but these have produced no visible change in the configuration of the land and sea; at any rate, no alteration has been noticed within historical times; and the handiwork of the prehistoric races is found on even the newest portion of the rising land.

It is thought that this small uplift has been general, and that it has affected the whole length of the coast-line. But in any case, the transition from the subsidence process to the uplift process may be irregular at first, and the uplifting may begin first in one place, then in another. Thus it is not surprising to find some coast-erosion still in progress, here and there. But these contacts with the waves are not extensive, and the sea does not appear to be making much advance in these places.

In comparing the Salinas with the Tablazos previously described, we must observe that this present episode is still incomplete. The subsidence and uplift which are evidenced, represent but a very small oscillation; and this may be only a minor incident preparatory to the making of an important Tablazo. Possibly several, or many, such oscillations as this occurred, and have left no trace, during the growth of the large Tablazos.

CHAPTER XL

UNRECORDED EPISODES

The several tablazos preserved are bound to give the impression of a series of diminishing episodes, for each marine transgression will obliterate any preceding tablazo that was not greater. The Lobitos Tablazo, for example, has narrowly escaped complete destruction during the Salina Episode.

Consequently the oldest tablazo (A) preserved, will simply be the largest one that has been produced ; the next oldest (B) that is preserved, will be the largest that has been produced since A ; and the third oldest (C) preserved, will be the largest produced since B ; and so on.

Hence, we have no proof that there have been only four of these episodes, or that the Mancora Tablazo was the first one. Indeed, in view of the magnitude of the Mancora Tablazo, it is probable that other lesser ones preceded it.

Thus the true history of the movements probably included many more chapters than the existing records are able to show.

SECTION F

THE QUATERNARY TERRESTRIAL DEPOSITS, AND THEIR RELATION TO THE MARINE TERRACES

CHAPTER XLI

INFLUENCE OF THE DESERT CLIMATE ON THE QUATERNARY MARINE DEPOSITS

The Tablazo Deposits were formed under circumstances which continue to the present day. The same creatures lived in the sea; and presumably the land has been a desert throughout the period. The peculiarities of the Quaternary marine formations are due to their accumulation on an oscillating continental shelf of a desert coast.

The region is practically devoid of rainfall. Between the Rio Tumbes in the north and the Rio Chira in the south, there are 140 miles of this arid coast-line in which not even the smallest stream enters the sea; and the clear ocean waters of the Humboldt Current are in contact with the shore. Thus the sea is rather free from mud, and limestones are produced quite close to the land.

The beds of Amotape stones, which are found in the Mancora Tablazo, and in some parts of the Talara Tablazo, were introduced into the sea by the floods

which occur two or three times a century. At the present day the Amotape stones, in great quantity, occupy the floors of the quebradas, in the middle of the map. But in the later episodes, owing to the greater distance between the mountains and the coast, the amount of Amotape stones which entered the sea has been less than in the days of the Mancora Sea.

The beach pebbles of Andean igneous rock, found in all the tablazos, have come from the south. As already explained, a fairly large river brought them into the sea, near the south-west corner of the map (see Chapter XVI.), and they were then drifted northward along the coast by the Humboldt Current of that day. At the present time, exactly similar stones are seen, in quantities, in valleys lying south-east of our area; and were traced to their source in the mountains there. At present the Rio Piura dries up before reaching the sea. (Pebble beaches are not frequent on the present coast.) But when the next flood period comes, both the Rio Chira and the Rio Piura will sweep a further supply of these stones into the present sea.

The wet seasons apparently occur at intervals of 25 to 50 years, when the prevalent climatic conditions break down, and the desert is swept by a violent flood.

Two floods are remembered by living inhabitants, occurring 31 years ago, and about 65 years ago; and the valleys, and their deposits, plainly show that these periodic floods have occurred frequently throughout Quaternary times.

The flood of 1891, brought about by daily torrential

rains in February and March, changed the face of the land considerably. The water poured down the deep mountain valleys, and immediately overflowed the quebradas, uniting as a great sheet which rolled on to the sea. New courses were cut; many drainage channels were changed; and an immense load of stones was swept down from the mountains to the plain below.

The processes of erosion and deposition now operating in this desert region present some interesting features; but in this paper (Part III.), attention is confined to the only desert accumulations which are of an enduring nature—namely, the breccia fans and terraces, deposited in years of flood.

CHAPTER XLII

THE BRECCIA FANS

THE principal accumulation formed in the desert during the Quaternary Period, is the great fan of breccia which surrounds the Amotape Mountains. (Figs. 36, 51, 52, 57, 59.)

This deposit has been produced by the periodic floods. Whenever one of these flood-years arrives, it finds on every hill-slope and valley-side, many years' accumulation of loosened and broken rocks, awaiting transportation.

Thus great torrents of mud and stones sweep down the mountain sides, and pour out from the mouth of every mountain valley, on to the plain. Here there is a sharp check to the velocity, and the greater part of the immense load of stones is dropped.

The main bulk of the Amotape Breccia Fan is the large cone produced by the floods which occurred after the uplift of the Mancora Tablazo. (See Chapter XXI.)

The greater part of this original Mancora Cone is still preserved; though in places the subsequent floods have dissected it and have eroded in it large breaches, in which they have deposited wide spreads and terraces of later breccia at lower levels.

Fig. 51.—Dissection of the Breccia Fan. (About lat. 12, long. 20.)

The Amotape Mountains are seen in the left and centre skyline. The surface of the Breccia Fan occupies the middle distance on the left and in the centre, and also the skyline on the right side of the picture. Deep dissection is seen in the foreground. The inclination of the surface of the Breccia Fan is perceptible. The view is taken looking southward.

Photograph by A. H. Low.

Fig. 52.—On the Breccia Fan, near the foot of the Amotape Mountains. (Probably about lat. 1, long. 15.)

Cerro Prieto, partially enveloped in mist, is seen in the distance. The low ridge in the middle distance is the first exposure of the Slates and Quartzites projecting up through the Breccia Fan. The bushes are *Algarroba*.

The form of the Mancora Cone is fairly regular. From the mouth of each of the mountain valleys a contributory cone of breccia debouches; and these all unite to form the one large Mancora cone or fan, which stretches far out into the plain. The contours on the surface of the Mancora Cone tend to be parallel curves, concentric with the mountains. The slope near the mountains is two or three degrees, and at a distance of three miles away from them it is about half a degree, the altitude decreasing by one or two hundred feet down to the tablazo level.

The Breccia Fan is composed of angular stones—mainly quartzite, slate, and spotted-slate, together with some granite and sand. The composition varies somewhat from place to place, according to the sources of the various cones which unite to form the fan. The fan is a massive deposit, having regular bedding and also current bedding. Near the mountains it has a thickness of 100-150 feet, and at a distance of 5 miles it is still 5-10 feet thick. Sections show it to consist of courses of varying character, some containing large stones, some made up of small stones, and some composed of gravel and sand. At the edge of the mountain the stones are large, blocks of several feet in length being numerous. Farther away the material becomes finer, so that at a distance of 5 miles the bulk of the stones are less than 4 inches and there is a larger proportion of gravel and sand.

The breccia deposit also extended back up the mountain valleys and up their tributaries, filling them completely to a depth of 100 feet or more. The

Ancha valley, for instance, was thus choked, up to a distance of 7 miles, back into the mountains, measured in a straight line. At this point, a vertical section may now be seen, showing 80 feet of breccia. When the floods subsided, the valleys remained "drowned" with stones, and must have presented the appearance of fiords in the mountains, with the deposit taking the place of water.

The surface of the fan is even, though stony; and it is generally good to ride upon; for almost every stone lying on the surface has been cracked up into fairly small pieces, by the heat of the sun. There is no vegetation except a few stunted bushes; and from afar, the ground has the look of red brown land which has been ploughed and harrowed, though a closer view shows that the ground consists of gravel instead of soil. The colour is always a rich rusty brown, due to the quartzite, whose surface weathers to this tint.

After the uplift of the Talara Tablazo, the floods carried their loads along the valleys which had now been cut down through the original Mancora Cone, and they deposited a fan of breccia over the newly raised land.

On account of the greater distance, much of the detritus was dropped in the valleys, and the fan which was spread out upon the Talara Tablazo is much less substantial than that on the Mancora Tablazo. Its thickness ranges from 10 or 15 feet, at its inland edge, down to 6 inches or less as we approach the present coast. The material is exactly similar to that of the earlier cone. Stones measuring 6-8 inches were

observed at a distance of 2 miles from the east margin of the Talara Tablazo.

After the Lobitos uplift, and again after the Salina uplift, similar events have occurred; but the amount of breccia which has travelled so far west as the Salina plains at present is very small.

CHAPTER XLIII

THE VALLEY TERRACES

THE only flowing river within our area is the Rio Chira (lat. −19) which crosses the south part of this desert. (Figs. 62, 63.)

The nearest river to northward is the Rio Tumbes (lat. 78), at the north border of the desert. It is very similar to the Rio Chira.

To southward the nearest river is the Rio Piura (lat. −38, long. 49), which dries up without reaching the sea.

All of these flowing rivers bring their waters from a part of the Andes behind the desert range; and to keep pace with the uplifts, they have cut gorge-like valleys.

Hundreds of other valleys and quebradas, however, dissect the desert; but they are dry in normal years, though in the occasional years of flood they are raging torrents.

A feature of these desert valleys is the system of terrace deposits which line them. Every quebrada, from the largest down to the smallest gully, contains terraces,—generally several terraces at different levels, which probably accord with the several uplift movements. (See Figs. 53, 54, 55, 56, and, in Part IV., Figs. 64, 65, 66, 67, 68, 69, 70, 71.)

Photograph by T O Bosworth

FIG. 54.—View looking south-eastward straight across the wide floor of Quebrada Ancha, showing the Terraces on the opposite side.

The edge of the Amotape Mountains is seen in the central and left background, the nearest and most conspicuous hill being Cerro Pan de' Azucar (elevation, 850 feet) (lat 5, long. 16) This hill is formed of the Pananga Limestone (Cretaceous). The skyline in the right background is the surface of the Breccia Fan.

The terraces have been formed in the periodic rainy years, the oldest dating back to the wet period which produced the Mancora Breccia Fan. At these times the streams are torrents of mud and stones. They are all greatly overloaded and must drop their load wherever the grade decreases or their velocity is checked.

The continual uplifting of the plains, the lengthening of the rivers at their seaward ends, the evaporation in the desert, and

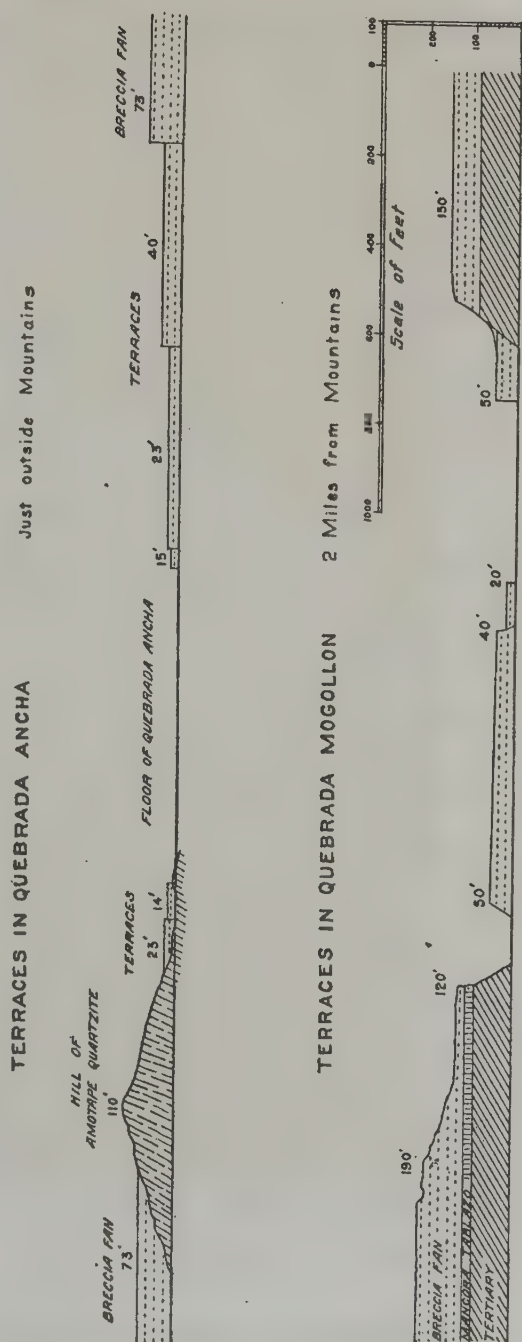


FIG. 53.—Sections showing Terraces in Quebrada Ancha and Quebrada Mogollon, near the Mountains.

the sudden abatements of the floods, all lead to the hasty formation of cones and fans and the filling up of the valleys with alluvium.

Later, when the floods have ceased, smaller and more constant streams continue to flow in the valleys for a few years, before the desert becomes completely dry again. These streams adjust themselves by cutting narrow, gorge-like courses through the cones and through the alluvium which had choked the valleys. Thus these stream-beds are lined with terraces of the former flood alluvium.

These terraces are bare and flat; and their edges are perpendicular cliffs, forming the descent from higher ones to lower ones, and from the lowest ones to the valley floor. Their height varies from 100 feet downwards.

The material of which the terraces are made is fully exposed in their vertical faces. It consists of angular stones, washed out from the Amotape Mountains and from the Breccia fans. The stones are of quartzite, slate, spotted-slate, and some granite, together with some gravel and sand. Within and near the mountains there is a large proportion of coarse material; and even at a distance of several miles away, some of the stones exceed a foot in length. The deposits are well stratified but are not compacted.

In the small quebradas and gullies near the coast, which rise only amongst the eroded Tertiary rocks, the terraces, though sometimes 50 feet high, are made principally of mud derived from the Tertiary, or of blown sand redeposited by water.

Commonly in areas where the valleys are over

Photograph by T. O. Bosworth.

Fig. 55.—Terraces in Quebrada Mogollon (lat. $8\frac{1}{2}$, long. $17\frac{1}{2}$), within a mile or two of the mountains.

The left foreground is on the same terrace which is so conspicuous on the opposite side of the valley. The floor of the Quebrada occupies the centre of the view. The trees are *Algarroba*. The right skyline is the surface of the Breccia Fan. The nearest of the mountains is prominent in the centre skyline.

Photograph by A. H. Low.

FIG. 56.—The Parinas Valley, looking across the valley northwards from a point half-way up the cliffs, on its south side.

The level surface of the Mancora Tablazo is conspicuous on both sides of th alley. It makes an almost continuous straight line extending right across the picture. On the skyline at the right margin, the Amotape Mountains are n sight. In the left half of the picture an extensive terrace is well seen in the distance, with a lower terrace in front of it.

100 feet deep, there may be three, or even four, distinct terraces, one above another, which are easily traceable for a number of miles. In some places they are seen on one side of the valley and in other places they are on the opposite side ; and frequently one is on one side and the remainder on the other side.

Correlation of the terraces in the different valleys may be possible, but is difficult on account of their number, their discontinuity, and the changes in their altitude as they are traced along the valleys.

The height of the terraces above the floor of the quebrada, was found to increase as they are traced inland towards the mountains and within the mountains. For example, in the Quebrada Ancha at the edge of the mountains, there are several prominent terraces, of which one of the lowest and least important has a height of 20 feet. But on following this terrace 7 miles upstream, it attains a height of 100-120 feet, having several smaller terraces below it. Its surface is the top of a large deposit of breccia which once choked up the mountain valley of the Ancha to this depth. The river since has cut through this breccia to its old floor (and a little deeper), so that the deposit is now seen as a terrace with cliffs 100 feet high.

The terraces in the mountain valleys are further complicated by local terraces with convex surfaces, which occur at the mouths of the tributary ravines. These are minor fans or cones whose lower ends have been truncated later by the main stream. Within the mountains, it is often not possible to decide between the deposit which belongs to the first great breccia fan and the deposits of later occasions.

In the broad, shallow quebradas which are the

western ends of valleys opening out on the Salina plains, there are wide, low terraces (sometimes ½ mile wide) which are uninterrupted for several miles. It is difficult to discriminate between these and the newest of the alluvial fans. Approaching the seaward end of the valleys, some terraces were observed to increase in height relative to the valley floor.

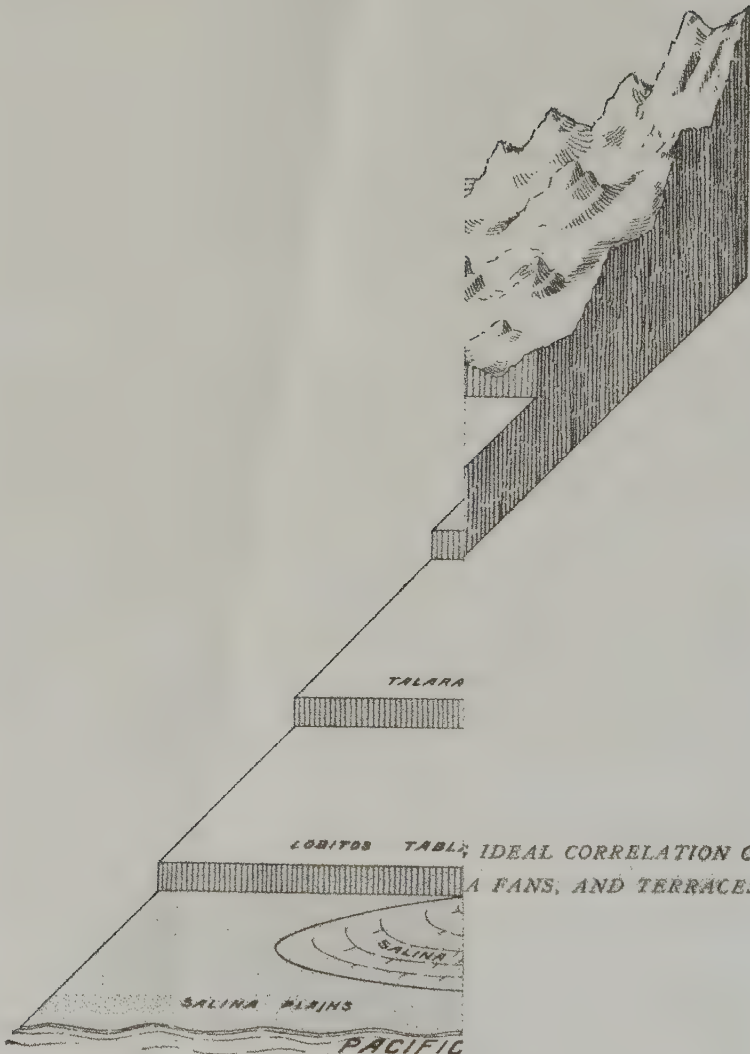
In the northern half of the desert, on account of the greater precipitation, the valleys are occupied by flowing water more often than are the valleys in the southern half. (In 1919 a stream flowed down Quebrada Parinas for several days.)

Owing to the larger amount of uplift in this part of the region, as well as to the greater erosion, the deepening of the valleys, after uplifting, has been greater. Consequently the channels have been cut down, not only through the valleys' own alluvial deposits, but also down into the Tertiary rocks beneath.

Thus in these quebradas the main terraces are seen as thick deposits of alluvial breccia resting upon benches cut in the Tertiary rocks.

Quebrada Honda (lat. 13) and Quebrada Parinas (lat. 9), which are the largest of these dry valleys, contain extensive terraces of this kind. (See Fig. 56.)

FOLDER No. VII.



IDEAL CORRELATION OF
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CHAPTER XLIV

CORRELATION OF THE FANS AND VALLEY TERRACES WITH THE MARINE TERRACES

THE more important quebradas are continuous into the mountains as deep valleys, which probably existed in Tertiary and pre-Tertiary times. But the Quaternary extensions of these valleys, outside of the mountains, have had a complicated history which is bound up with that of the tablazos. (See Folders VII. and VIII.) This history is outlined below:

In a previous chapter (Chapter VIII.), we have seen that immediately before the earliest of the tablazos first began to rise from the water, the sea (Mancora Sea) reached almost to the Amotape Mountains.

Accordingly the valleys were graded originally for entry into the sea not far from the foot of the mountains. (On the diagram, Fig. 57, see curve AB.)

But after the Mancora uplift, when next the torrents came down from the mountains, they had to traverse a new plain, 20-30 miles wide (Mancora Tablazo), before reaching the ocean (the Talara Sea). Consequently velocity was checked and a great part of the load of stones and gravel was dropped, its disposition being such as to grade the course to

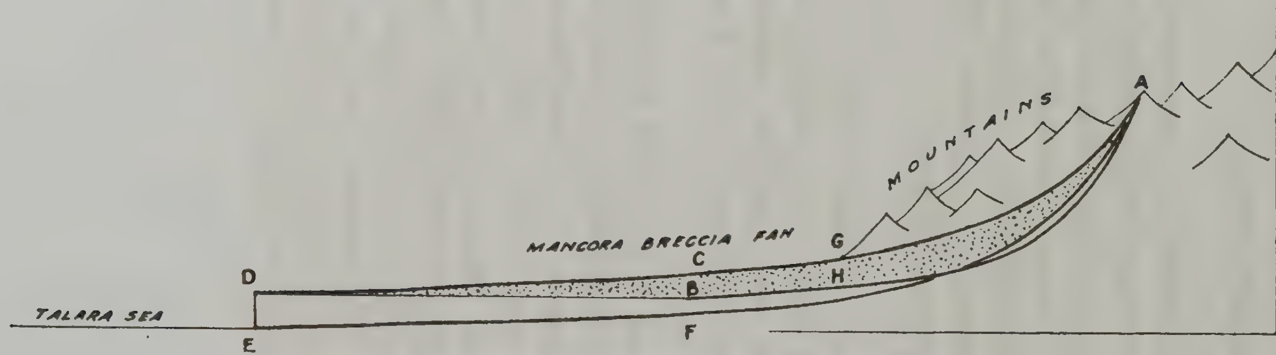


FIG. 57.—Diagram to show formation of Breccia Fan and Terraces.

EXPLANATION.

AB	Original profile of river entering Mancora Sea at B.
BD	Mancora Tablazo surface after uplift.
GCDBH	Breccia Fan deposited by flood after uplift.
AGHA	Extension of alluvium back up mountain valleys, drowning them.
AGCD	Base curve of erosion between A and D, thus temporarily achieved by deposition.
AFE	New base curve of erosion between A and E, established when river had cut down through Tablazo to sea-level and deepening had progressed back from sea to mountains.
AG	After river had cut down through its own flood-alluvium, the remnants in the mountain valley appear as terraces. Their elevations accord with curve AG.

the new conditions. (See curve ACD.) (See also Folders VII. and VIII.)

This deposit is the Mancora Breccia Fan, which extended far out over the plain and also back up the mountain valleys, drowning them. Doubtless the process was gradual, and some of the floods which contributed to it occurred before the uplift was complete.

As might be expected, this state of things was only a temporary measure. Very soon, definite channels were established on the plain, and the river set about the business of cutting itself a valley into the new land. This deepening of the channel was commenced at the seaward end and progressed upstream in the ordinary manner, so that in due time the bed of the watercourse was graded down to the proper curve (base line of erosion) from the new seashore (Talara Sea) to the mountains. (See curve AFE on diagram.) When this was done, the river had cut down through its own alluvial fan and valley deposit. (The rejuvenation possibly also had enabled it to cut down a little deeper into the solid rocks than before.)

The newly cut watercourse was a narrow trench-valley, as above described. It is bounded on either side by perpendicular cliffs of the material previously deposited. (The cliffs are now discontinuous, but remnants are generally present on one side or the other.)

Meanwhile many new rivers and tributary rivers also came into existence, due to the rainfall on the breccia fan and on the tablazo. These streams established valleys which gradually cut back from

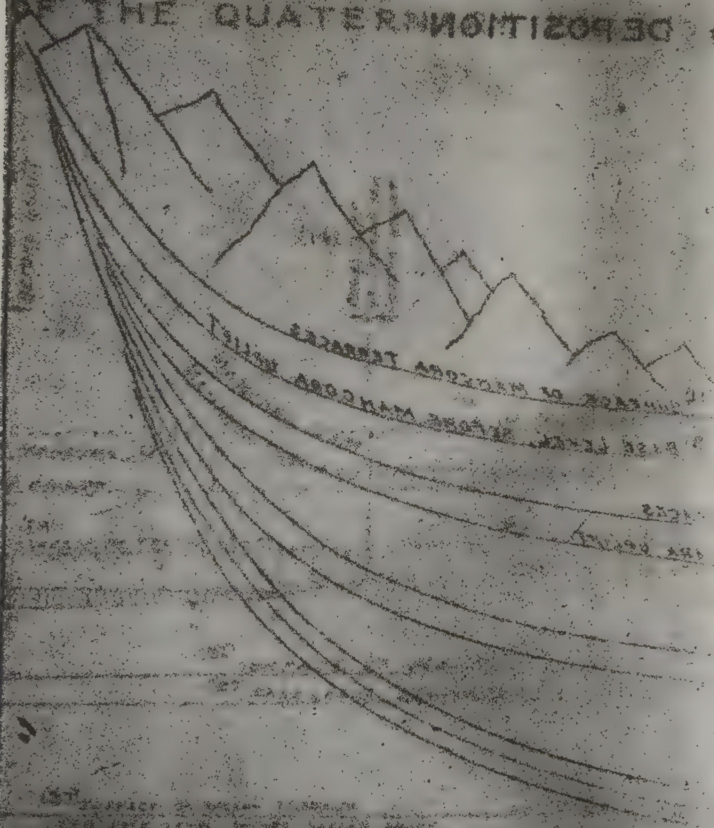
the sea or from the main valleys, and have much dissected the tablazo and the fan.

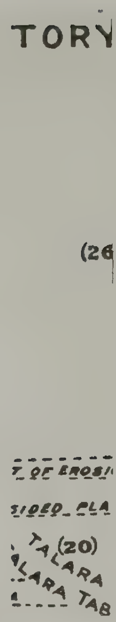
When the next uplift occurred (Talara Uplift), there was a repetition of the above process, though on a smaller scale; and the rivers, which had adjusted themselves to flow into the Talara Sea, now found in front of them a new tablazo land, 10-20 miles wide (the Talara Tablazo), which must now be traversed before the ocean (the Lobitos Sea) could be reached.

Forthwith, at the old mouths of these rivers, where they now entered upon the new tablazo (Talara Tablazo), alluvial cones were deposited, merging together and spreading over almost the whole of the Talara Tablazo, as the Talara Breccia Fan.

These new deposits also extend back up the valleys —just as the previous breccia fan extended back up the mountain valleys.

In time the rivers again cut down to the new base level, and the deepening was extended from the sea to the source. All along the valleys, up into the mountains, terraces remained, formed of the flood deposit which preceded this deepening. Theoretically, their surfaces all are parts of one surface, continuous with that of the Talara Breccia Fan; and the elevations should be in accordance with the base-curve of erosion. But actually, both the uplift movement and the erosion by flood, took place by stages, intermittently; consequently a number of terraces were produced, and it is impossible to exactly correlate all the data. Theoretically, every movement produced a fan, and every terrace is the up-valley continuation of a fan. (See Folders VII. and VIII.)

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The uplift of the Lobitos Tablazo, which next occurred, was followed by similar events. Again the rivers were lengthened at their mouths, and again they cut down to base-level of erosion. Thus again the deepening was carried back from the new sea's coast-line to the source, and new sets of terraces were left,—5, 10, 20, or 40 feet in height.

The present uplift of 10 feet also has had effects of the same nature as the others. Thus there are small alluvial fans at the mouths of all the quebradas which open on to the Salina Plains; and even the smallest gullies and watercourses show low-level terraces like the others.

The above is merely an outline sketch of the events. The irregularities in the uplift processes, the intervening subsidences, the variable character of the floods, and the casualties to drainage channels (due to capture, diversion, overflow, etc.) (see p. 286), would render the full truth far more elaborate.

SECTION G

SUMMARY OF THE QUATERNARY GEO-HISTORY

CHAPTER XLV

QUATERNARY TIME

In conclusion, it is interesting to consider the immensity of geological time. In the foregoing chapters we have traced the Quaternary history of a small piece of the earth's crust.

At the commencement of this period the creatures which inhabited the waters were the same as those of to-day; and the land and sea, the mountains and the desert, must have appeared very much the same then as now. Geologically speaking, the beginning of Quaternary time was but as yesterday.

Yet during this so recent period, great cycles of events have occurred and recurred, and great processes have been carried out. In this period the earth's crust has been moved upwards and downwards hundreds of feet again and again. The sea has advanced and retreated many times, cutting its cliffs into the land, 10 miles or 20 miles on each occasion.

In intervals between uplifts, hundreds of feet of limestone have been deposited, some of which now stands a thousand feet above the level of the sea.

On the land, deep valleys have been carved, in which elaborate systems of terraces have been produced; and fans and cones of alluvium, a hundred feet thick, have been deposited.

The well-defined cycle of processes, described in the preceding chapters, is still in operation; and there is no reason to suppose that there has been any retardation of them in recent years.

Yet within historic times, the movement has been imperceptible. The newest of the uplifted land—only a foot or two above the high-tide line—was under cultivation in the days of the Incas; and the small earth tremors which sometimes occur, have left no mark. Within the last century there have been only three wet seasons to set the rivers flowing; and on the floors of some of the valleys, footprints, made nearly thirty years ago, are still intact.

In conclusion, it seems almost safe to estimate that not a ten-thousandth part of the Quaternary history, outlined in these pages, can have taken place in the last five hundred years.

CHAPTER XLVI

SUMMARY AND APPROXIMATE OUTLINE OF THE QUATERNARY HISTORY

THE most western ranges of the Andes are of pre-Tertiary age. The Eocene Pacific Ocean lay at the foot of them.

In the Tertiary Period a large but gradual subsidence was in progress, during which a great thickness of shallow-water deposits accumulated.

The Amotape Mountains are the peaks of a once lofty range which is now partially submerged in the Tertiary deposits.

In the interval between the Tertiary Period and the Quaternary Period a new movement occurred, along a great fault-belt parallel with the Andes. The east border of this geo-fault belt passes along the foot of the Amotape Mountains. The west border is a few miles out to sea along the edge of the continental shelf.

The mountainous land on the east side of the fault-belt was uplifted thousands of feet, whilst the sea-floor on the west side of the fault subsided to great depth.

The uplifting of the mountains caused a strip of

territory along the west side of them, roughly 20 miles wide, to emerge from the sea. This is the Littoral. It bears 20,000 feet of Tertiary strata.

The present Littoral and continental shelf is intensely block-faulted. It was the crush-belt of the geo-fault.

Throughout the Quaternary Period the Littoral (together with the mountains) has undergone a series of vertical oscillations. The Littoral has been lifted up and down repeatedly like a lid, having its edge a few miles out in the Pacific Ocean and its hinge line in the Andes.

During these processes the Littoral, several times, has been alternately overspread with a marine deposit and then raised above the sea.

The ocean soundings show a steep 2000-foot submarine cliff at the edge of the continental shelf. This follows a fairly direct line which passes within 5 miles of the land (at Cabo Blanco and at Punta Parinas). This cliff is taken to be a submarine fault-scarp, marking the important fracture which was the western boundary of the Quaternary Uplifts.

This Pacific Fault Line probably was in existence also during the movements which terminated the Tertiary deposition. It may have been the main axis of the geo-fault.

The resultant of the Quaternary movements is an uplift. The oldest and highest of the raised sea-beds now has an altitude ranging from 200 feet, in the south of our map, up to 1100 feet, in the north of it.

The raised sea-beds, within the confines of our special area, extend 12-16 miles inland and occupy,

or have recently occupied, 1000 square miles. The original western boundary of the deposit was the western margin of the continental shelf.

Whether there was any oscillation of the deep sea-floor on the west side of the fault is not known. The depth, 27 miles from the present coast, is 12,000 feet. The Quaternary deposits formed upon it, presumably are deep-sea oozes.

The events on the east side of the Pacific Fault may be grouped into four similar episodes. Each consists of a subsidence accompanied by marine transgression, followed by an uplift causing emergence of new land from the sea. They are as follows :

The Mancora Episode.
The Talara Episode.
The Lobitos Episode.
The Salina Episode.

During subsidence the sea is able to cut into the land, carving out an extensive plain of marine erosion. While the sea-cliff is continually advancing eastward, the plain of erosion behind it is sinking continually deeper. After the plain of erosion sinks below the limit of wave erosion a marine deposit grows upon it.

When subsidence is ended and uplift is in progress, the sea gradually retreats, abandoning its line of cliffs and its beaches. As the uplift continues, the new-formed marine deposit, which covered the plain of marine erosion, gradually emerges from the sea, in the form of a plateau or "tablazo"—which is a raised sea-floor.

If the uplift continues long enough, the whole sea-floor, from the abandoned cliff to the Pacific Fault, will emerge as dry land.

With the next episode, the sea again advances upon the new land, pushing forward a new line of cliffs, carving out a new plain of marine erosion, and at length forming a new tablazo to seaward of the first one and at a lower level.

The Mancora Episode.—This marine transgression extended inland 14 miles from the present coast. The final shore-line, before the sea retreated, is within a mile or so of the mountains.

The subsidence amounted to several hundred feet, as shown by the presence of 300 feet of sediment upon the plain of erosion, at the most western part of it which is revealed.

The preserved part of the Mancora Tablazo, within our map, is a tableland 80 miles in length and 10-12 miles wide.

Its present height ranges from 1100 feet at its north end, near Mancora, down to 200 feet in the south of our map, at Payta.

The surface of the Mancora Tablazo was the bed of the Mancora Sea. It is strewn with sea-shells and with the beach pebbles of the retreating sea. Remains of whales are found upon it.

The uplift, which concluded this episode, amounted to about 900 feet in the north and 150 feet in the south.

The Talara Episode.—Subsidence was at length resumed, and the sea again advanced. The new plain of erosion extended inland 9 miles from the present coast.

The final shore-line, before the sea retreated, is

marked by a well-defined line of cliffs, 100 feet high, with the old sea-beaches at their foot.

The thickness of the deposit formed on this plain of erosion is generally less than 20 feet.

A "fossil river," underneath the Talara Tablazo, gives definite evidence that the subsidence was not less than 100 feet.

This is a river-deposit, filling an old gorge-like valley, 100 feet deep, cut in the Tertiary rocks. The deposit merges up into the normal marine tablazo bed, which rests on the erosion plane on either side of the valley, and which is continuous right across the river deposit. The plain of marine erosion is 100 feet above the old valley floor.

The preserved part of the Talara Tablazo is a tableland, 25 miles in length and 4-8 miles wide. The height is about 280 feet in the north, and 135 feet at the southern end.

The surface of the Talara Tablazo was the bed of the Talara Sea. It is similar to that of Mancora Tablazo.

The uplift which concluded this episode amounted to 180 feet in the north and 55 feet in the south.

The Lobitos Episode.—Subsidence again ensued and the sea again advanced its cliffs, carving out a new plain of marine erosion, which extended inland not more than four miles from the present coast.

The amount of subsidence is not known; the greatest thickness of the deposit, found on the plain of erosion, is 20 feet.

The final shore-line, before the sea next retreated, is marked by the old sea-cliffs; of which some small,

but perfectly preserved, remnants are still found. The line of them, on our map, can be traced about 60 miles.

The Lobitos Tablazo was once a continuous plateau; but only small portions of it escaped destruction during the next episode. The largest has a length of 7 miles.

The uplift movement which raised this tablazo amounted to 100 feet.

The Salina Episode.—A subsidence, of unknown quantity, enabled the sea to make another transgression, destroying much of the Lobitos Tablazo, and carving out a new plain of erosion at a lower level.

An uplift followed, which is still in progress, and has at present only amounted to about 10 feet.

The line of abandoned cliffs, in places, is now two miles inland.

The newly emerged land consists of coastal plains. At highest tides, the sea floods some parts of these plains; and after evaporation they are covered with white salt.

Other Episodes.—Each episode obliterates all traces of any preceding one which was not greater. Only four episodes have left their mark, but probably a number of others occurred, especially before the Mancora transgression.

The Quaternary marine deposits, formed on the subsiding planes of marine erosion, are peculiar. They consist chiefly of loosely compacted shell-limestone and pebble beds.

Much of the shell-limestone is highly charged with

large beach pebbles, of 1-4 inches diameter. This rock varies from pebbly shell-limestone to calcareous shelly conglomerate.

The pebbles are of three distinct kinds, named below in order of abundance. In some beds the three kinds are mixed, but more often they occur separately.

(*a*) Andean Volcanic Rocks—Andesites, porphyrite, basalt, etc. These are derived from mountains south-east of our area, and were brought into the sea by a river, north of Payta. They were then drifted along the coast, northward, by the Humboldt Current. A layer of these beach pebbles forms the surface of each tablazo. It was left by the retreating sea.

(*b*) Amotape Stones—quartzite, slate, spotted-slate, and a little granite. These were derived from the Amotape Mountains near at hand.

(*c*) Tertiary Pebbles—quartz, quartz-schist, porphyrites, etc. These were derived from pebble seams in the underlying Tertiary beds.

A desert climate has prevailed during the period, interrupted, at intervals of 25-100 years, by violent floods. The most recent flood occurred in 1891.

The country is much dissected by dry valleys or canyons, known as quebradas. The valleys are "trench-shaped," having flat floors and perpendicular sides. Some are 800 feet deep. They are characterised also by the extensive development of terraces.

After the uplift of the Mancora Tablazo, the first

floods deposited a Breccia Fan, 100 feet thick, at the foot of the mountains. This fan or cone spread far out over the tablazo and also extended back up the valleys, drowning them to a depth of 100 feet. It consists of angular stones, measuring up to 2 feet or more. They are of quartzite, slate, and spotted-slate. This deposition accomplished temporary adjustment of the grade to the new conditions.

Soon, rivers cut down through the tablazo to sea-level, two or three hundred feet; and the deepening of the valleys was pushed back inland, so that the rivers cut deep courses through their own alluvial cone, and through the deposits which had drowned their mountain valleys.

After the uplift of the Talara Tablazo, when floods again occurred, another similar adjustment was performed.

Where the rivers had previously entered the sea, they now poured out upon a plain. Thus a Breccia Fan, 20-5 feet thick, was spread out upon the Talara Tablazo; and this deposit also extended back up the valleys, choking them.

Again the rivers cut down through the new tablazo to sea-level; and again the deepening was pushed back inland, so that the streams cut courses down through their own new fans and through the deposits which had drowned the older parts of their valleys. The remnants of those deposits are now seen as terraces along the valley sides.

After each uplift this process was repeated. First, a fan was formed at the old mouth of each valley, and the valley was partially choked up with alluvium. Then the stream established a channel across the new

land, and cut down to sea-level; next the deepening was extended upstream. Each terrace in the valley is a remnant of the alluvium that once choked the valley.

The valleys contain many terraces. Commonly two or three and sometimes four are seen, having altitudes ranging up to 100 feet. Within the mountains the valleys contain conspicuous terraces at 100, 25, and 15-5 feet.

The terraces are in fine preservation, with flat bare surfaces and perpendicular cliffs. They are composed of alluvial breccia.

Theoretically, the several tiers of terraces are the up-valley continuations of the several fans. They should correspond to various base lines of river erosion which were adjusted to the different seas. But the number of the terraces and their discontinuity make it difficult to classify and correlate them.

Wind erosion is very severe in parts of the desert, but no desert accumulations of an enduring character have been formed except the breccia deposits, which have been laid down by water.

Finally, it is concluded that the Quaternary events, outlined above, must have occupied a period of many millions of years.

PART IV

DESERT CONDITIONS AND PROCESSES IN THE DESERT OF TUMBES, PERU

By T. O. Bosworth, D.Sc., M.A.

CHAPTER I

GENERAL OUTLINE OF THE DESERT

The territory under consideration, known in Peru as the Desierto de Tumbes, is the most northerly of that long chain of deserts which extends along the Pacific coast of South America, occupying the country between the Andes and the ocean.

This desert, though small, is one of the driest and most desolate. Between the Rio Tumbes in the north and the Rio Chira in the south, there are 140 miles of arid coast-line, in which not even the smallest stream enters the sea.

The desert is roughly 50 miles wide and 120 miles in length. (See map, Folder No. I., in Part I.) To northward it is bounded by the Rio Tumbes, about $3\frac{1}{2}°$ south of the Equator; beyond which we soon pass into the moist tropical vegetation of Ecuador. To southward it merges into the Desierto de Sechura. The inland border is indefinite; for besides the whole of the Littoral, the desert includes also the outermost of the mountain ranges—the Cerros de Amotape and Cerros de Payta. Farther inland, beyond these desert mountains, are the loftier ranges in which precipitation occurs, and from which the Rio Tumbes, Rio Chira, and Rio Piura bring their water.

Whilst conducting a geological[1] survey of this region, during the period 1912-1920, the author has spent some two years camping in this desert, and has thus had good opportunity to observe the desert processes.

Superficially, the following six kinds of territory are traversed, in turn, as we cross this desert, from the mountains to the sea.

1. Desert Mountains.

   The Cerros de Amotape and the Cerros de Payta are rugged mountains, rising steeply to altitudes of 5000 feet. The range is of pre-Tertiary age, and is composed mainly of slates and quartzites and intrusive granite.

2. Desert Breccia Fan.

   This is a large cone of coarse stony flood-detritus, surrounding the mountains. It dies out on the plateaus next mentioned.

3. Desert Plateaus.

   These "tablazos" are pebbly plateaus, having altitudes mainly 200-1200 feet. They are Quaternary marine terraces, formed of sheets of horizontal shell-limestone, having thickness 10-250 feet. Their elevation is the result of successive uplift movements. They once covered almost all the country from the sea to the mountains, and still occupy more than half of it.

4. Bad-lands.

   Much-dissected ground, from which the horizontal Quaternary cover has been denuded.

[1] Paper read before the Geological Society of London, Dec. 15, 1920.

These hilly areas are carved in the Tertiary shales, sandstones, and pebble seams. The Tertiary deposits, some 20,000 feet thick, occupy all the Littoral from the sea to the mountain flank, which was their shore-line. They are intensely block-faulted, and are variously inclined at angles ranging up to 40°.

5. Salinas.

Sand-plains and salt-marshes, nearly at sea-level. These are areas from which the sea has been recently withdrawn, by reason of slight uplift of the land.

6. Coastal Dunes.

Ridges of dunes along the coast of the Salinas, having altitudes up to 40 feet.

Cause of the Desert Climate.—The desert climate is probably a consequence of the Humboldt Current. This current, bearing cooler waters from the south, sweeps powerfully along this most westerly part of the continent. After passing Cabo Blanco, it begins to swerve seaward, due to the warm Ecuador current, which is bearing down against it from the north. The Humboldt Current keeps the temperature of the sea, along the coast of our area, some 6 or 7 degrees lower than it otherwise would be. Consequently the very cool air from the sea (which is ever moving landward to replace the hot air rising from the land), when it reaches the land, is quickly raised to a temperature considerably above its saturation point; it then passes on over the land, absorbing with avidity every particle of moisture that can be found. Not until the distant high mountain ranges

are reached, is the temperature cooled down to the point at which ordinary precipitation can occur.

Indices of Locality used in these pages.

On the accompanying maps (Folder No. I. in Part I., and Folder No. IV. in Part III.) lines of latitude and longitude have been drawn at 10-mile intervals, for purpose of reference. The initial point from which they are numbered is Punta Parinas, the most western cape of South America. From north to south, some of the noteworthy places are :

Rio Tumbes :	a small river with villages along it. Lat. 81, long. 63.
Tumbes :	a small town. Lat. 77, long. 61.
Zorritos :	an oilfield on the coast. Lat. 70, long. 48.
Mancora :	a small village. Lat. 40, long. 22.
Cabo Blanco :	a headland at which the general direction of the coast-line changes. Lat. 29, long. 6.
Lobitos :	an oilfield on the coast. Lat. 16, long. 4.
Quebrada Parinas :	an important dry valley. Lat. 10.
Talara :	a port of the oilfields. Lat. 7. long. 3.
La Brea :	a landmark 12 miles inland. Lat. 1, long. 13.
Negritos :	an oilfield on the coast. Lat. 1, long. 2.
Punta Parinas :	the most western point of South America. Lat. 0, long. 0.
Rio Chira :	a small river with villages along it. Lat. –16.
Amotape :	an old village on the River Chira. Lat. –15, long. 21.
Sullana :	a small town. Lat. –30, long. 44.
Payta :	a seaport. Lat. –13, long. 14.
Rio Piura :	a small river which dries up before reaching the sea. Lat. –38, long. 49.
Piura :	a small town of political importance. Lat. –38, long. 49.

Photograph by T. O. Bosworth.

FIG. 58.—Cerro Prieto (3000 feet) in the Amotape Mountains.

The mountains in this view are composed of Amotape Slates and Quartzites. The parasitic plant *Tupeia* is seen on the stunted bushes in the foreground. Many of the cactus *Gigante* are seen in left half of the picture.

CHAPTER II

THE WORK OF WATER IN THE DESERT

PRECIPITATION.

The rainfall in the Desert of Tumbes in normal years is practically nil.[1] There has been no considerable rain for about thirty years.

By the seaside, however, there may be one or two sprinkles of rain in the year; and every evening after sunset, owing to the rapid cooling of the air, there is a slight mist along the sea-shore, which wets the ground.

On the peaks of the Amotape Mountains there is some precipitation, chiefly in the form of a heavy mist,—though not sufficient to give rise to any running stream. The process is visible from the plains; for towards sunset, small clouds are seen forming in the air, as it approaches the mountains; and these grow rapidly larger as they drift onwards with the wind, and soon they completely cover the mountain tops (Fig. 59). At this time it becomes cold and wet on the mountains, and continues so until the clouds are dispersed by the sun, at from 8 to 10 o'clock in the morning.

Towards the northern end of the desert, beyond

[1] Describing this region in 1532-50, Pedro de Cieza de Leon wrote that "it never rains" (*Travels of Pedro de Cieza de Leon*).

Mancora, the aridity is less severe, and in some places inland there is a little running water—which, however, does not reach the sea.

Two or three times a century the prevalent climatic conditions break down, and the desert is swept by a violent flood.

Two floods are remembered by living inhabitants, occurring thirty-one years and about sixty-six years ago; and the valleys and their deposits plainly show that these periodic floods have occurred frequently throughout Quaternary times.

The flood of 1891 was brought about by daily torrential rains in February and March. The water poured down the deep mountain valleys and immediately overflowed the quebradas, uniting as a great sheet, which rolled on to the sea. Many drainage channels were changed, and an immense load of stones was swept down from the mountains to the plain below. For two years afterwards the country was moist and green, so that herds of cattle and goats were introduced, and also cotton was planted. In the next two years the country dried up again completely, the vegetation died, and the cotton gin became a curio.

Although rainfall is so rare, the desert, nevertheless, bears almost everywhere the impress of water erosion.

The forms of the mountains are not abnormal, though they are rather more angular and rugged than is usual. The valleys in the higher parts of the mountains are sharply V-shaped and their sides

Photograph by A. H. Low.

FIG. 59.—On the Breccia Fan, near the foot of the Amotape Mountains, east of La Brea.

The foreground is occupied by the Breccia Fan. The low ridge in the central part of the view is the first exposure of the Amotape Slates and Quartzites. It is surrounded by the Breccia Fan, and has been almost buried by it. In the background are Cerro Prieto and other mountains of the Amotape Range. The vegetation is *Algarroba*. A bank of clouds is seen enveloping the mountain summits.

Photograph by T. O. Bosworth.

FIG. 60.—Dew-hole in Granite, Amotape Mountains. (Altitude 3000 feet.)

Tupria, growing on the stunted trees, is seen in flower, overhanging the hole.

Photograph by T. O. Bosworth.

FIG. 61.—Dew-hole in Granite.

On the granite mass of Cerro Buenos Aires, at altitude about 3000 feet.

are very rough; but, except that they are bare and dry, they do not look peculiar. In the lower parts of the mountains, however, the valleys are lined with terraces and have the trench form described below. The great silence in the mountains is one of their most noticeable features.

On the desert plateaus—the tablazos—there are innumerable trench-like watercourses, and it is seldom possible to travel for a mile or two without encountering them.

In the bad-lands the intricate dissection is clearly the work of water. Here the crests of the ridges, however, are sharper than in wet climates, and the outlines of the hills are steeper and less curved.

The characteristic decoration of the slopes by countless little runnels, results from the lack of vegetation. In moist climates, vegetation binds the surface-matter, and by acting as a sponge, it puts a check on such hasty drainage. But here, where the slopes are bare and dry, whenever rain suddenly descends, a great number of little streams immediately trickle down them, each stream quickly etching for itself a diminutive channel in the loose, crumbling, surface-rock.

It is in the wind-swept plains that the work of running water is the least perceptible—for here the constant wind erosion (which will be described below) has often wholly or partially effaced all marks of the water erosion which preceded it.

THE FLOOD DEPOSITS.—*The Amotape Breccia Fan.*

The principal accumulation formed in the desert is the great fan of breccia which surrounds the Amotape

Mountains. (See Figs. 59 and 110, and also Figs. 36 and 51 in Part III.)

This deposit has been produced by the periodic floods. Whenever one of these flood-years arrives, it finds on every hill-slope and valley side, many years' accumulation of loosened and broken rocks awaiting transportation. Thus great torrents of mud and stones sweep down the mountain sides, and pour out from the mouth of every mountain-valley on to the plain. Here there is a sharp check to the velocity, and the greater part of the immense load of stones is dropped.

The pile of breccia which now surrounds the mountains is constructed of various component parts, representative of the several episodes of the Quaternary and Recent Period; but for convenience the whole accumulation may be termed the Amotape Breccia Fan.

The main bulk of the Amotape Breccia Fan is the large cone adjacent to the mountains, which rests on the oldest and highest of the Quaternary marine terraces (Mancora Tablazo). Presumably this cone was formed early in the Quaternary Period, when this earliest portion of the Littoral had newly emerged from the sea. (See Chap. XXI. in Part III.)

The greater part of this original (Mancora) cone is still preserved, though in places the subsequent floods have dissected it and have eroded in it large breaches, in which they have deposited wide spreads and terraces of later breccia at lower levels.

The form of the Mancora Cone is fairly regular. From the mouth of each of the mountain valleys a contributory cone of breccia debouches; and these

all unite to make the one large cone or fan, which stretches far out into the plain. The contours on the surface of this cone tend to be parallel curves, concentric with the mountains. The slope, near the mountains, is two or three degrees (see Fig. 51 in Part III.), whilst at a distance of three miles away from the mountains it is about half a degree, the altitude decreasing by one or two hundred feet, down to the tablazo level.

The whole Breccia Fan is composed of angular stones — mainly quartzite, slate, and spotted-slate, together with some granite, and also some sand. The composition varies somewhat from place to place, according to the sources of the various contributory cones. The fan is a massive deposit, with regular bedding and current bedding. Near the mountains it has a thickness of 100-150 feet; and at a distance of five miles it is still 5-10 feet thick. Sections show it to consist of courses of varying character, some containing large stones, some made up of small stones, and some composed of gravel and sand. At the edge of the mountain the stones are large, blocks several feet in length being numerous. Farther away the material becomes finer, so that at a distance of five miles the bulk of the stones are less than four inches and there is a larger proportion of gravel and sand.

The Mancora Breccia deposit also extended back up the mountain valleys (see Figs. 68, 69, 70) and up their tributaries, filling them completely to a depth of 100 feet or more. The Ancha Valley, for instance, was thus choked, up to a distance of seven miles back into the mountains, measured in a straight line. At this point a vertical section may now be seen showing

80 feet of breccia. When the floods subsided, the valleys remained " drowned " with stones, and must have presented an appearance resembling fiords in the mountains, with the deposit taking the place of water.

The surface of the fan (see Fig. 59 and Fig. 36 in Part III.) is even, though stony; and it is generally good to ride upon, for almost every stone lying on the surface has been cracked up into fairly small pieces by the heat of the sun. There is no vegetation except a few stunted bushes; and from afar the ground has the look of red brown land which has been ploughed and harrowed, though a closer view shows that it consists of gravel instead of soil. The colour is always a rich rusty brown, due to the quartzite, whose outside weathers to this tint.

After the emergence of the succeeding marine terraces (Talara Tablazo and Lobitos Tablazo) the next floods carried their loads along the valleys which had now been cut through the original cone, and they deposited a fan of breccia over the newly raised land. (See Part III., Chapters XXX. and XLII.)

On account of the greater distance, much of the detritus was dropped in the valleys, and the fans which were spread out upon the lower tablazos are less substantial. The thickness ranges from 10 or 15 feet, at the inland edge, down to six inches or less as we approach the present coast. The material is exactly similar to that of the earlier cone. Stones measuring 6-8 inches are seen at a distance of two miles from the inland margin of the second marine terrace (Talara Tablazo).

Photograph by A. H. Low.

FIG. 62. View in the valley of the Rio Chira, 1¼ mile from the mouth of the river, looking northward across the floor of the valley from the south side of it, near Pueblo Nuevo. (Lat. 21, long. 24.)

Along the right skyline the profile of the Amotape Mountains is faintly visible. Extending right across the picture, in the background, is the 300-foot cliff which is the north bank of the valley. The Mancora Tablazo bed makes the flat top of the cliff. Its surface is a bare desert plain. The south cliff of the valley is behind the observer; it is similar to the north cliff. The right foreground is occupied by blown sand, which has drifted down from the desert surface of the Tablazo behind the observer. The vegetation occupying the valley floor is chiefly *Algarroba*. In the distance the river is perceptible, crossing the picture, from right to left. This verdant valley appears as a wide trench, cut through the desert surface of the Tablazo to a depth of 300 to 400 feet.

Photograph by A. H. Low.

Fig. 63. The Rio Chira at Sullana (lat. 15, long. 11), 30 miles inland; looking north-eastward across the river, from the foot of the south cliff. The northern cliff is seen in the distance.

THE FLOWING RIVERS AND THEIR VALLEYS.

The only flowing river within our area, is the Rio Chira (lat. −19), which crosses the south part of this desert (Fig. 62 and Fig. 63).

The Rio Chira has a width of 300-700 feet, with depth generally 4-6 feet, and in places 10 feet. The velocity is 4-5 miles an hour; and at the seaward end there is a fall of 160 feet in 40 miles (rough measurements only).

To keep pace with the uplifts, where the Chira river crosses the tablazo plains it has cut a gorge-like (though fairly wide) valley. It is possible to stand on the bare desert surface of the tablazo, on either side of the valley, and look across at the normal continuation of this desert plateau on the other side, without seeing that a river lies between. Yet within a few yards of the observer's foot is the precipitous edge of the river-cliff; and on looking down there is seen, 250 feet below, a verdant strip of land, a mile or two miles wide, bounded on both sides by the bare desert rampart, and winding away into the far distance, where it appears as a dark streak in the grey of the desert.

The nearest river to northward is the Rio Tumbes (lat. 78), at the north border of the desert. It is very similar to the Rio Chira.

To southward the nearest river is the Rio Piura (lat. −39, long. 49), which dries up without reaching the sea.

All of these rivers bring their waters from a part of the Andes behind the desert range.

THE INTERMITTENT RIVERS AND THEIR VALLEYS.

The desert is much dissected by hundreds of dry valleys or quebradas which, in the occasional years of flood, are occupied by raging torrents of mud and stones. These valleys present some interesting features which are due to—

1. The torrential character of the floods;
2. The brief duration of the flows;
3. The desiccation of the streams.

SHAPE OF THE QUEBRADAS.

The valleys in the desert are "trench shaped." Their sides are steep cliffs, often almost vertical except where slipping has occurred; and their floors are flat, all the way across, from the cliff or terrace on the one side to the cliff or terrace on the other side.

Many of the quebradas are 200 or 300 feet deep, and some in the north are 500-700 feet deep. Commonly they are very narrow in proportion to their depth. But where the quebradas traverse the lower plains near to the sea, they may be a quarter or half a mile wide, with the walls only 5-10 feet high.

The country is much cut up by large numbers of these quebradas and their tributaries, and since many of them are impassable for miles of their courses, travelling transverse to the direction of drainage is difficult. But the floors of the larger quebradas are seldom interrupted by falls, and it is generally possible to ride along them on a horse or mule.

The pre-Quaternary parts of the valleys which are within the mountains, were originally of the normal V-shaped pattern; but they have since been partially

Photograph by O. D. Boggs.

Fig. 65.—Terraces in Quebrada Parinas. (About lat. 12, long. 16.)

This view of the north side of the valley is taken from a point half-way up the cliffs, on the south side. The present watercourse, strewn with white sand, is in the foreground. Bordering it, there is a belt of *Algarroba* trees. Behind the trees there is an extensive terrace, and at the left side of the picture a higher terrace. The whole of the skyline is occupied by the Mancora Tablazo.

O. D. Bogg

FIG. 66.—Extens rrac Quebrada go lon, where i en ers Quebrada Parinas.

filled in, to a depth of 100-150 feet, with stony alluvium; and the present channels which have been cut in this accumulation, are trench-shaped quebradas, similar to the valleys in the plains.

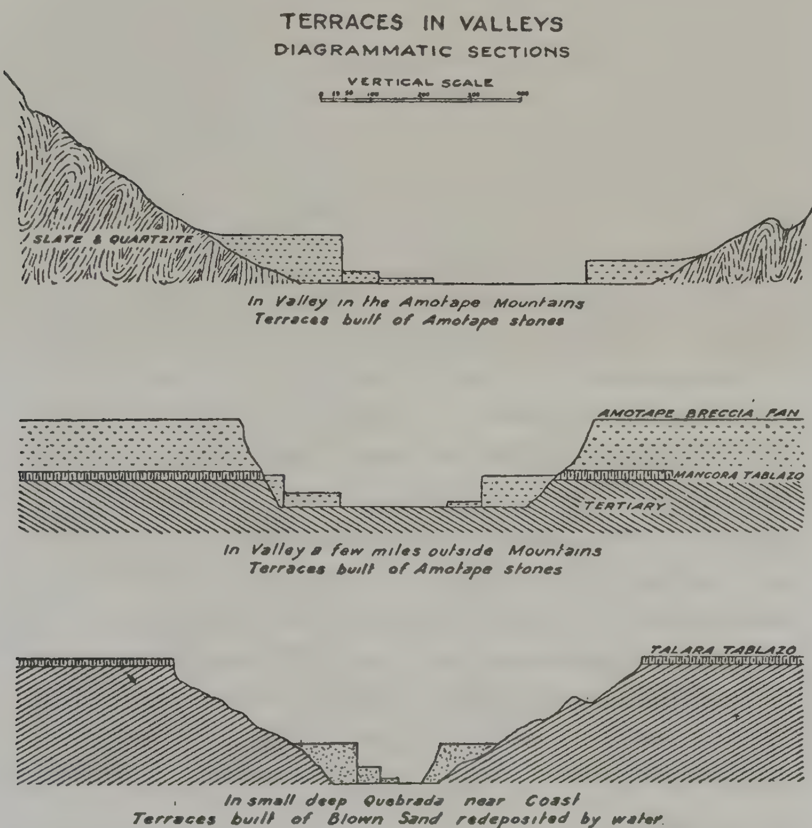


FIG. 64.

TERRACES IN THE QUEBRADAS.

Every valley, from the largest down to the smallest gully, is more or less lined with terraces—and generally with several terraces—which are the remains of deposits formed in years of flood.

The streams which come down these valleys at

flood times, are described by those who have seen them as rivers of mud and stones. They are already excessively overloaded when they flow down from the mountains, and all along their course additional debris lies awaiting transportation. At the same time the water is being absorbed into the parched ground and is being evaporated in the hot desert air. Soon, also, the supply of water abates.

Under such conditions, erosion is impossible and the stream can but achieve a temporary grading by the immediate deposition of its load. And so each valley and gully is quickly filled, or partially filled, with the alluvium.

Later, when the floods have ceased, smaller and more constant streams continue to flow in the valleys for a few years, before the desert becomes completely dry again. These streams adjust themselves by cutting narrow, gorge-like courses through the cones and through the alluvium which had choked the valleys, thus leaving them lined with terraces.

These terraces are bare and flat, and their edges are perpendicular cliffs forming the descent from higher ones to lower ones, and from the lowest ones to the valley floor. Their height varies from 100 feet downwards.

The material of which the terraces are made is fully exposed in their vertical faces. (See Fig. 69.) It consists of angular stones, washed out from the Amotape Mountains and from the Breccia Fans. The stones are of quartzite, slate, spotted-slate, and some granite, together with some gravel and sand. Within and near the mountains there is a large preponderance of coarse material; and even at a

Photograph by R. G. Sammons.

Fig. 67.—Terraces in a quebrada, tributary to Quebrada Mogollon.

The mountains are seen in the right background. The valley is cut through the Breccia Fan and the Parinas Tablazo bed, and into the Tertiary rocks beneath. The sloping surface of the Breccia Fan is seen in profile.

Photograph by I. G. Bosworth.

Fig. 68.—Section of a Terrace, 60 to 70 feet high, in Quebrada Ancha, within the Amotape Mountains.

The height decreases as the terrace is traced down the valley; just outside the mountains it is only 20 feet. The terrace is composed of stones.

distance of several miles away, some of the stones exceed a foot in length. The deposits are well stratified but are not compacted.

In the small quebradas and gullies near the coast, which rise only amongst the eroded Tertiary rocks, the terraces, though sometimes fifty feet high, are made principally of mud derived from the Tertiary, or of blown sand redeposited by water.

Commonly in areas where the valleys are over 100 feet deep, there may be three, or even four distinct terraces, one above another, which are easily traceable for a number of miles. In some places they are seen on one side of the valley and in other places they are on the opposite side; and frequently one is on one side and the remainder on the other side.

The height of the terraces above the floor of the quebradas was found to increase as they are traced inland towards the mountains, and within the mountains. For example, in the Quebrada Ancha at the edge of the mountains, there are several prominent terraces, of which one of the lowest and least important has a height of 20 feet. But on following this terrace seven miles upstream it attains a height of 100-120 feet, having several smaller terraces below it. Its surface is the top of a large deposit of breccia which once choked up the mountain valley of the Ancha to this depth. The river since has cut through this breccia to its old floor, so that the deposit is now seen as a terrace with cliffs 100 feet high.

The terraces in the mountain valleys are further complicated by local terraces with convex surfaces, which occur at the mouths of the tributary ravines. These are minor fans or cones, whose lower ends have

been truncated later by the main stream. Within the mountains, it is often not possible to decide between the deposit which belongs to the first great Breccia Fan and the deposits of later occasions.

Approaching the seaward end of the valleys, some terraces were observed to increase in height relative to the valley floor.

In the broad shallow quebradas, which are the western ends of valleys opening out on the Salina plains, there are wide low terraces (sometimes half a mile wide) which are uninterrupted for several miles. It is difficult to discriminate between these and the newest of the alluvial fans.

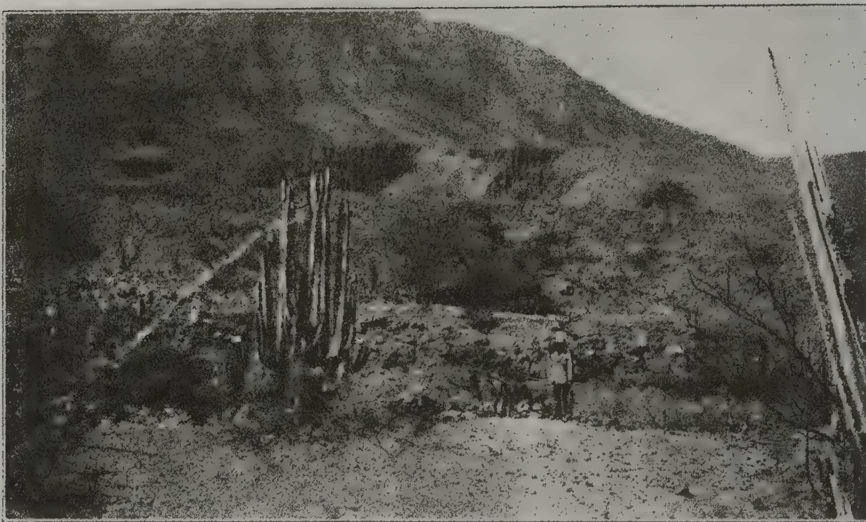
In general, the deposit comprising a later fan can be traced back into the area of the preceding fans, as a terrace extending up the valleys which have traversed the preceding fans. (See Folder No. VII. in Part III.) The relationship between the fans and terraces and the uplifts, is discussed in Part III., Chapter XLIV.

CAPTURE, DIVERSION, OVERFLOW, ETC.

Owing to the earth movements, the intermittent flows, and the great mass of alluvium, many of the drainage channels have met with interesting casualties. Diversion and capture have been frequent; and in places, streams have lost their way in the quebradas choked up with alluvium, and have cut narrow gorges from one valley into another. (See Fig. 71.)

Photograph by T. O. Bosworth.

Fig. 69.—Section of a Terrace in Quebrada Ancha, within the mountains, showing character of the deposit.



Photograph by T. O. Bosworth

Fig. 70.—Terraces in Quebrada del Muerto, within the mountains, near their edge.

The cactus on the left is the species known as "*Gigante*."

Photograph by T. O. Bosworth.

Fig. 71.—A watercourse which has "lost its way," in a valley "drowned" with alluvium (breccia).

The smooth, pale area, stretching right across the picture, is the surface of the breccia deposit.

A more recent water-channel has been cut into this deposit This is the lowest ground in the centre and right part of the picture, just beyond the pale area, and bearing many stunted bushes.

This place is a few miles distant from the mountains; the view is taken looking towards the sea. The desert plains are just visible on the centre skyline

The later stream has lost its way, and instead of continuing down the valley, to the left, it has cut a gorge (seen in the centre background) through the Eocene rocks which formed the side of this valley: and has escaped into another valley

CHAPTER III

THE WORK OF THE SUN IN THE DESERT

Temperature.

The temperature along the coast is moderated by the breeze from the sea. In the district of Punta Parinas, records[1] show the daily maximum in summer to be 88°-98°, and in winter 70°-76°, whilst the daily minimum is about 76° in summer and 60° in winter. Inland, however, it is much warmer, and in some parts of the desert the shade temperature commonly exceeds 100 degrees.

In the mountains the nights are cold, especially near the summits, which are enveloped in mist; but at about eight or nine o'clock in the morning when the sun disperses the clouds of mist, the temperature may rise from 50° up to 100° within an hour or two.

Sun-split Stones.

The sun's heat is a very active agent of disintegration.

The effect is strikingly displayed on the pebbly surface of the tablazos. Here the smooth rounded beach-pebbles, lying just as they were deposited, are fractured into many pieces. They tend to be

[1] In the shaded porch of a house at Negritos about 50 feet above sea-level.

broken into thin vertical slices transverse to their longest axis. Usually the parts remain in place, and with care the broken pebble, though perhaps consisting of 10 or 20 slices, may be lifted up complete. These sliced stones occur in profusion. (See photographs, Figs. 73, 74, 75, 76.)

Where the surface of the tablazos have been more disturbed by wind and water, the angular, sun-cut, and also wind-cut, pieces of stone are scattered far and wide.

On the surface of the Breccia Fan the same action occurs. Blocks of quartzite two or three feet in length, lying just where the last flood-water left them, are now fractured into a number of large pieces ; and lesser stones are parted into still smaller bits. These stones do not undergo the same regular slicing as the Andean beach pebbles, but are broken into irregular angular shapes.

The extreme angularity of this flood breccia marks the important part which the sun has played in its production. It was largely the heat of the sun that loosened the rocks and broke them up, upon the mountains, until the flood-waters could remove them ; and then subsequently, in the quebradas and on the Breccia Fan, the sun has been continually breaking up the stones into smaller fractions, and so enabling further transportation.

At a distance from the mountains the material of the Breccia Fan resembles machine-crushed quartzite, such as is used for roads. (It is rather like the heaps of Hartshill quartzite which are a familiar sight on roadsides in southern England.)

Fig. 72.—Exfoliation of a quartzite pebble, caused by the heat of the sun. (Reduction = ½.)

Fig. 73.—Sun-sliced pebble, from surface of an outcropping Tertiary pebble-seam. (Reduction = ½.)

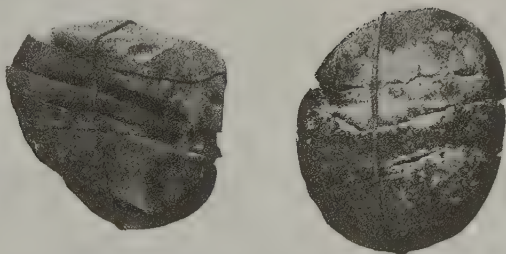
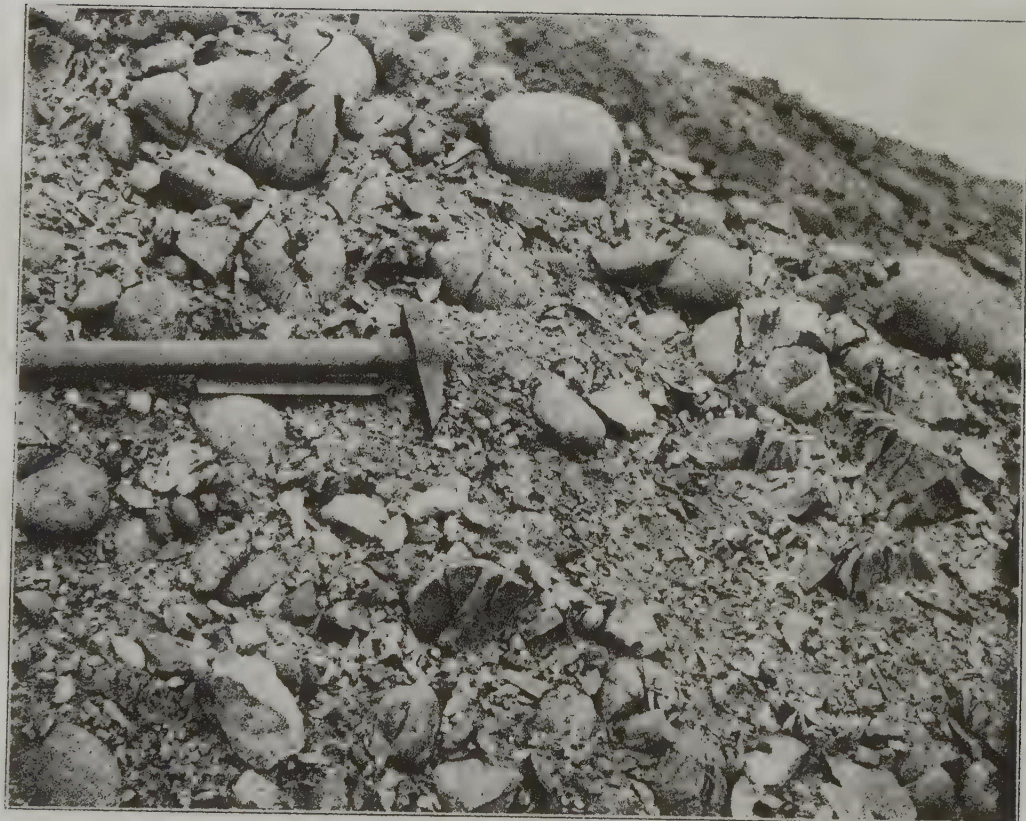


Fig. 74.—"Sun-sliced" pebbles. (Reduction = ½.)

Fig. 75.—Another view of the same "sun-sliced" pebbles. (Reduction = ½.)



Photograph by T. O. Bosworth.

In the hills formed by the Tertiary beds also, the sun is active in disintegration, the effect on the exposed pebble-beds being especially conspicuous. In the daytime the stones become so hot that it is painful to touch them for more than a moment. Sometimes almost every pebble at the surface of a bed is sliced (see photograph, Fig. 76), and if the exposure lies at a fairly steep angle, as is generally the case, the smaller bits produced are in process of removal by wind and gravity.

Salt and Selenite on the Salinas.

The Salinas, which have been referred to already, are sandy plains which have recently been abandoned by the sea. The sea is now shut off from them by coastal dunes—but in parts they are moistened by sea-water percolating into them, and in places they are flooded, at high spring-tides, by the sea breaking in through some gap in the coastal dunes. The largest of these Salinas extends along the coast, south of Punta Parinas, for 20 miles. Others, of some importance, occur farther south at Colan; and to northward just beyond Mancora.

In the Salina south of Punta Parinas, there is at the present time an area of about a square mile which is periodically flooded by sea-water. The heat of the sun on the Salinas is intense, and in the course of a few days the water is evaporated, leaving the surface covered with a snow-white deposit of salt (Fig. 78), about half an inch deep. In a few more days this salt is absorbed or dispersed by wind, and only crystals of selenite remain (Fig. 80).

The evaporation process, which was closely ob-

served on a number of occasions, took place as follows. After the inflow, when the tide subsides, the water on the Salina is about six inches deep. With the commencement of crystallisation, ridges are developed which divide up the floor into roughly hexagonal cells, measuring several feet across. At first these ridges do not reach the surface of the water—but soon the corners appear above the water, and then with further upgrowth of the ridges, the cells of water soon become isolated (Figs. 77 and 78).

The hexagons are irregular, though the corners almost invariably are the starting-points from which three sides radiate, making three angles of 120°. It is suggested that each of these corner-points is initiated by the projecting corner of a cubic crystal of salt; and that the hexagonal arrangement is a consequence.

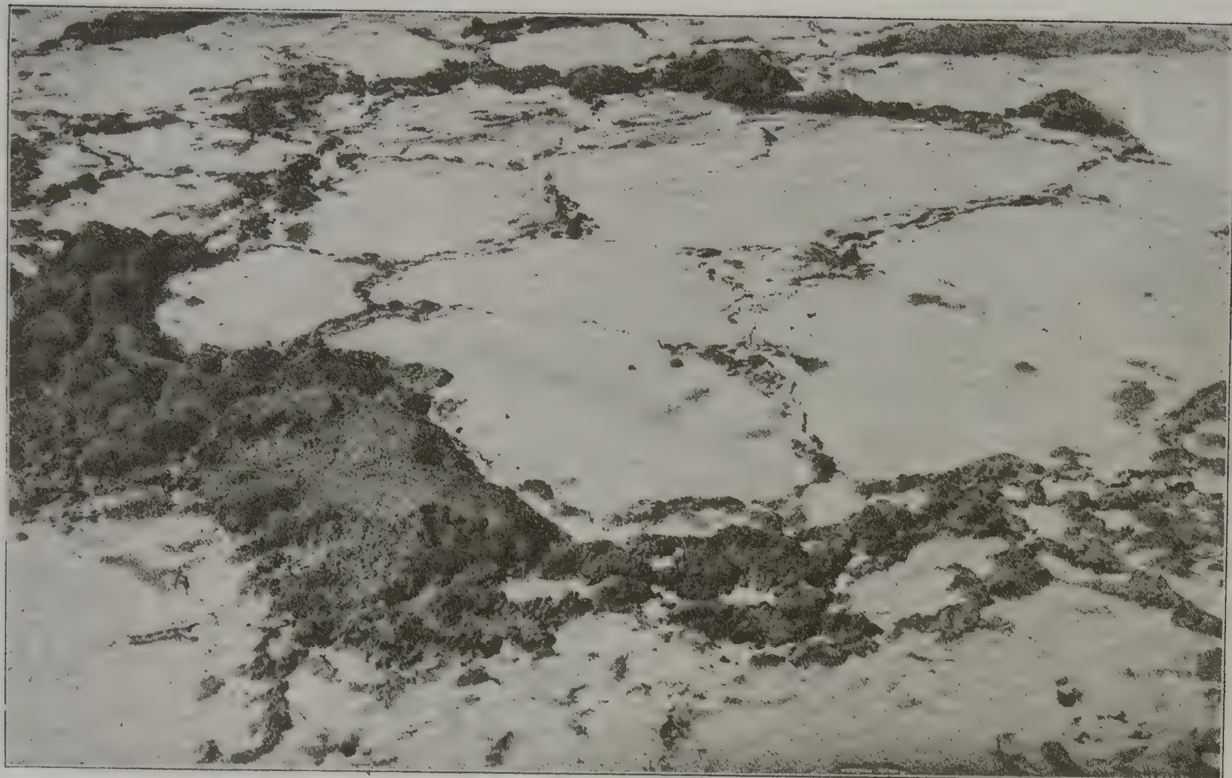
In the middle of each cell, beautiful cubic crystals are formed under the water. The size of them is about a quarter of an inch, but some measure as much as one inch. At the edges of the cells the crystallisation is less perfect.

Next, as evaporation proceeds, a film of finely crystalline salt spreads over the surface of the water, growing outwards from the walls—and at last, when the water disappears, this growth settles over, and covers, the more perfect crystals below.

In many of the cells, light wind ripples are caused in the deposit. The crystals here are small and are specially segregated on the crests (Fig. 79).

The ridges which part the cells, vary in size. Generally they are 2-6 inches wide. Some are covered with salt.

After about ten days all the water has disappeared.



Photograph by G. D. Boggs.

Fig. 77.—The hexagonal mud-cells, filled with salt, which are developed on the Salina after it has been flooded by the Spring Tide.

Photograph by T. O. Bosworth.

FIG. 78.—Salt on the Salina, after it has been flooded by the Spring Tide.

The cellular arrangement is well seen.

But on digging a hole, brine came up to within about three inches of the surface. After a few more days, when this test was repeated, the water was three inches lower.

On desiccation in the Salina, the salt soon loses the perfection of its crystallisation; and in a few days it commences to be mixed up with drifted sand.

The ridges which parted the cells now burst open, a wide crack trending medially along them. This is brought about by a curling up of the flanks of the ridge. No crystals other than the salt were found in the cells or in the ridges during the above-described events. But as the ridges dry up and the salt is disappearing, some small crystalline shapes appear which much increase the ruggedness of these ridges. Wind and blown sand pick these out in relief, and day by day they become more numerous and conspicuous. Soon they occur also on the floors of the cells, among the slight residue of the salt (Fig. 80). The floors become rough, and miniature sand dunes form on the lee side of each nugget.

The larger of these forms, measuring, say, half an inch or one inch, are composed mainly of sand; but smaller ones are of fairly clear crystal. These now appear on the surface in large numbers, as small separate crystals. They are drifted by the wind, and in places, hundreds of them are collected together. These are crystals of selenite of unusual form. Some of the crystals are more than one inch wide, but many of them measure about three-eighths of an inch. There also are very many of still smaller size.

Many of them appear like very obtuse rhombohedra and have hexagonal outline. They are formed mainly

by the equal development of four *l* faces (1, 1, 1) and two *c* faces (0, 0, 1). Some of the larger crystals have very sharp edges and possess only these six faces. But most of them show also a thin strip of the *b* face (0, 1, 0).

The crystals have a green-blue tinge of colour. They grow in all positions, but tend to lie flat.

The growth of selenite, in these plains, appears to be continuous, long after the salt has gone;—but this particular type of crystal was found only in these special circumstances.

On digging into the damp sand, in places from which the salt had gone, hard prisms an inch or more in length were found, down to a depth of six inches. These are composed of sand with crystalline cement, and are of the common form.

In other parts of the Salinas which are no longer flooded by the sea, many large rough crystals of selenite occur on, or within, the surface. These are of the usual form, and are sometimes six inches or more in length.

In the desert-weathering of the Tertiary clay-shales, much gysum is produced. Most of it occurs in thin sheets composed of vertical fibres. Bedding planes, joint-planes, crevices, and fault-planes often are lined with these sheets and thin slabs; and pebbles, lenticles, and calcitic veins may be encased by the same material. Occasionally there is so much of this substance that quantities of it have slipped down the slopes and resemble heaps of broken glass.

Photograph by T. O. Bosworth.

Fig. 79.—The salt cubes and ripples in the salt deposit on the Salina.

The scale, lying on the ground, is opened to a length of 12 inches.

Photograph by T. O. Bosworth.

Fig. 80.—The peculiar Selenite Crystals growing on the Salina, after the salt has gone.

The scale, lying on the ground, is opened to a length of 6 inches.

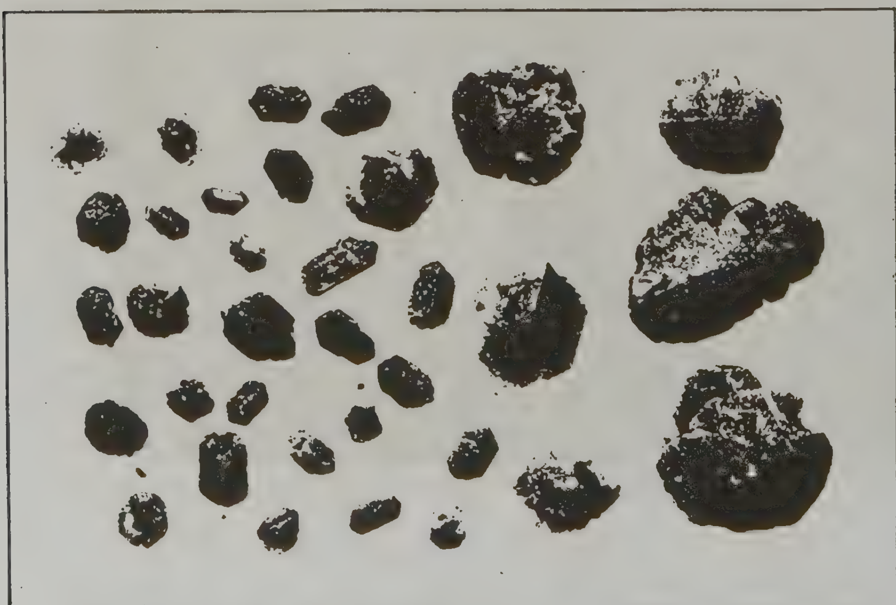


Fig. 81.—Sample of the Selenite Crystals which grow on the Salina, in a few days after the salt has gone. (Natural size.)

CHAPTER IV

THE WORK OF THE WIND IN THE DESERT

THE WIND.

SOME parts of the Desert of Tumbes have been intensely eroded by blown sand, and in almost all parts there is some wind deposition.

The wind blows principally from the south-west. There is a fairly regular diurnal variation of its intensity and also of its direction. There are two maxima and two minima in the twenty-four hours. The greater of the maxima occurs between 3 and 4.30 in the afternoon, and the lesser one in the early hours of the morning. At these times the wind blows strongly from the south-west. The two corresponding minima are at about 8 o'clock in the morning and 8 o'clock in the evening, at which hours the wind is only very light and comes from the south-east.

The above variation of intensity follows a smooth curve, and the change in direction takes place gradually. The cycle recorded by the barometer shows a daily range of pressure of about ·13 inch (observations at Negritos in February).

It is the strong wind from the south-west and

south,[1] blowing during the afternoons and sometimes during the early mornings, that have produced the effects which are to be described below.

During the winter months, April to July, this wind commonly amounts to a light gale, which sometimes prevails throughout the whole day.

WIND-CUT STONES.

It is noticeable that wind erosion has been least on the tablazo plains, and is greatest on that territory which the flood-streams have dissected into hilly ground and bad-lands. It is apparent that the plane surfaces offer least resistance, and so suffer least erosion.

The pebbles of Andean igneous rocks on the surface of the tablazos, however, are intensely wind-cut by the drifting sand. They are cut to elaborate shapes, with curved facets and sharp edges and points. The new surfaces are highly polished. If part of the original rounded surface of the pebble is preserved, it may often be seen that only a small fraction of the pebble now remains. (See photograph, Fig. 32 in Part III.)

The cutting of these pebbles may continue until they are reduced to small sharp particles, which are carried away by the wind, as sand. These particles are conspicuous among the drifted sand, on parts of the Salina plains bordering the tablazos (Fig. 83). In places, rifts of them have been sorted out by the wind. Mainly, they are splinter-like, bright bits of black basalt, having many small polished facets and sharp points and angles.

[1] It was recorded by the Spanish conquerors that the wind blows always from the south in this region. (*Travels of Pedro de Cieza de Leon*, 1532–50.)

Fig. 82.—Fossils, ground and polished by blown sand, from surface of an outcropping fossil-bed, about 2 miles west of La Brea. (Reduction = ½.)

In each of these specimens nearly half the fossil has been cut away, exposing the interior of the shell.

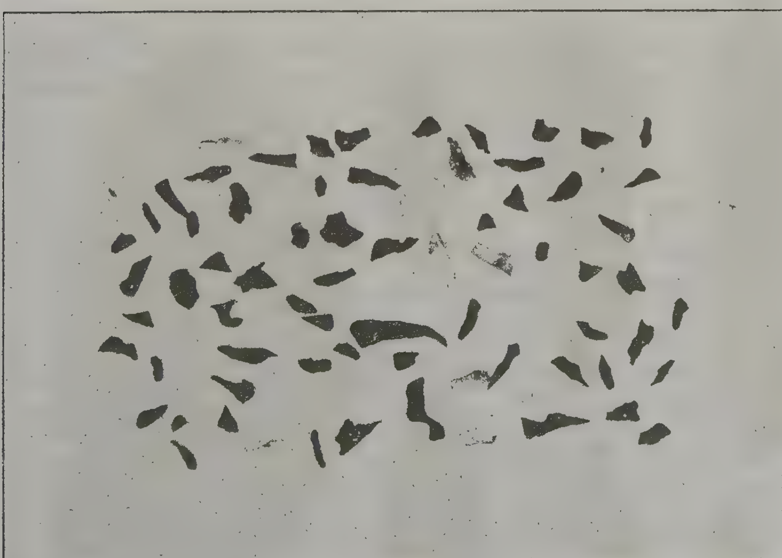


Fig. 83.—"Splinter Sand," consisting of particles of pebbles which have been reduced, by sun-splitting and wind-cutting, to such small size that they are drifted away by the wind. (Natural size.)

The black particles are fragments of the Andean Pebbles which lie on the surface of the Tablazo.

Fig. 84.—Black Dreikanters, cut out of Andean Pebbles, on the surface of the Mancora Tablazo. (Natural size.)

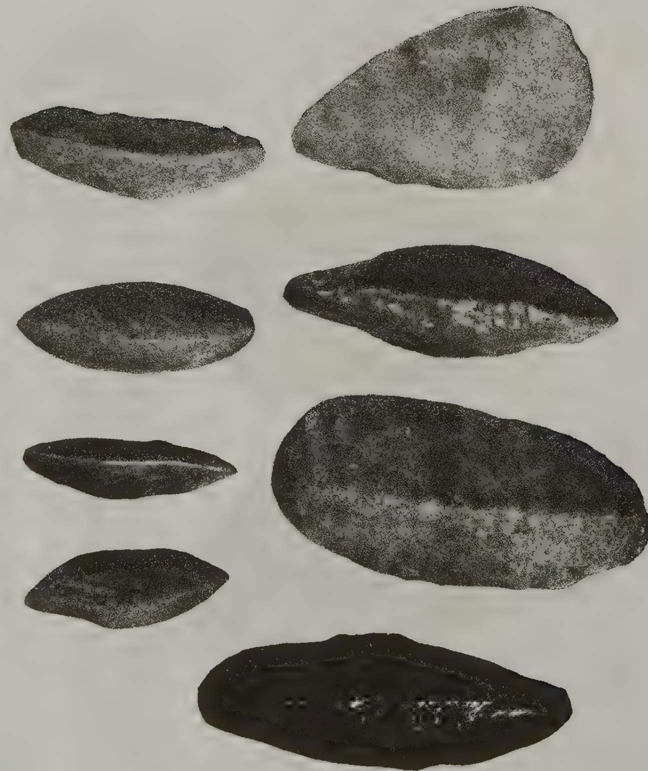


Fig. 85.—Dreikanters, cut out of white quartzite pebbles, on a little plateau in the Cerros de Payta. (Natural size.)

Dreikanters of imperfect shape (Fig. 84), 1-4 inches in length, are fairly common, but those of symmetrical pattern are scarce. In one locality, however—a little pebbly plateau on the flanks of the Payta Mountains (lat. – 35)—at an elevation of a few hundred feet above the tablazo—quantities of unusually perfect dreikanters, cut out of quartzite pebbles, were observed. (See photograph, Fig. 85.) The best of these are little more than an inch in length and are of slender outline.

THEORETICAL CONSIDERATION OF WIND EROSION.

To determine the ideal stream-line form for a hill, we seek for that shape which, resting on a plane, offers zero resistance to a stream of a perfect fluid moving with uniform velocity. This is the same mathematical problem as finding the ideal shape for a ship's hull, except that the circumstances are inverted. The solution is a form resembling the hull of a racing yacht turned upside down. It varies somewhat according to the velocity of the fluid—a more slender outline corresponding to the greater speed. In a perfect fluid such a hill would offer zero resistance. It would be the ultimate product of wind erosion.

In air, of course, the total avoidance of friction is not possible. But the shape thus mathematically determined, or something nearly identical, is the form which offers *minimum* resistance. In the following pages it is referred to as a "windform."

When an obstacle has not this ideal shape, a body of "dead air" attaches itself, to make up the missing parts. Then, if the air were a perfect fluid, this "dead air" would be parted from the moving air by

a surface of perfect kinetic discontinuity, and the wind would pass by without experiencing any resistance. Thus the irregular shape would offer no more resistance than the windform shape.

But since the air is not a perfect fluid, but has viscosity, there is friction at the surface of discontinuity, and minor currents are formed in the dead air and in the moving air, which conflict and cause loss of energy. Hence the irregular-shaped obstacle offers more resistance than the stream-lined body; and the currents around it operate, by erosion and deposition, to bring it to the "windform" shape.

When the wind encounters a mass of hills, it must dispose itself in many different currents, passing over and among and around the hills, with various directions and velocities. At first this system of currents is very complex—and the more complex it is, the more energy is lost in friction between the currents,—besides the friction with the rocks.

The wind erosion works to better these conditions. Gullies and notches are cut, ravines are widened or deepened, slopes are smoothed, debris is removed, and the front of the hill mass is dissected.

The currents are continually readjusting themselves among the hills so that the streams are those to which the hills can most readily be stream-lined, whilst the streams proceed to correct the whole outlines of the hills so as to give them shapes which offer least friction to the motion. The air currents were adjusted to the hills and now the hills are being adjusted to the air currents.

This stream-lining is brought about partly by

Photograph by T. O. Bosworth.

FIG. 86.—Ridge-and-furrow Topography, produced where the strike of the beds is in the same direction as the prevalent wind.

The view shows principally three ridges, with straight parallel crests. (Owing to the photograph having been taken in two parts, the parallelism is not so conspicuous as it should be.) The right-hand ridge was named "Straight Edge." We see the scarp face of the left-hand ridge, the dip-slope and a little of the scarp face of the middle ridge, and the dip-slope of the right-hand ridge. The dip-slope in each case is formed by a single thin seam of pebbles and shells. That of the right-hand hill contains an abundance of *Cerithium Chatwini* (sp. nov.). The three ridges terminate, near the front of the picture, against a transverse fault, which conspicuously crosses the entire view, from left to right. The foreground is occupied by parts of another group of ridges, on which the observer is standing. The strata belong to the Turritella Series of the Negritos Formation, 1 mile east of Negritos.

Photograph by T. O. Bosworth.

erosion and partly by deposition—corners and points are worn down here and there, whilst in other places sand is deposited to build up " keels " and " tails," etc.

In time, more or less perfect "stream-line" forms may be produced—forms not identical with the ideal "windform" (which was stream-lined for a uniform stream), but somewhat similar forms which are just as perfectly adapted to this particular arrangement of air currents, and individually offering minimum resistance.

Further improvements will simplify the currents until at length the wind has become more nearly a uniform stream, and the hill mass has been reduced to a number of isolated little hills of windform shape, all parallel to one another, facing the wind.

In nature the conditions are far from ideal. The air has viscosity, the rock is not uniform, and the wind is inconstant. Hence no hill, no matter how closely its shape approaches perfection, can be secure from further erosion. In the end, a bare plain, at sea-level, is produced.

(It is to be noticed that erosion below sea-level may occur temporarily in places where the sea cannot gain access—but, with the advance of the denudation, the barriers eventually will be dissected, and the sea-level is the final limit.)

WIND EROSION IN THE DESERT OF TUMBES.

Among the hills of Tertiary clay-shale, the erosion by the wind often is visibly active. The sand is seen driving and scouring along the slopes, and streams of small particles and dust are being visibly carried away from the hill.

It is to be observed that much of the wind erosion is performed without the aid of sand. The sun's heat disintegrates the rock ; the wind removes the particles.

Sometimes after a stormy night there is a perceptible change in the colour of the wind-swept hills ; for all the worn, pale grey particles of shale which were at the surface, have been blown away, and a complete fresh surface is exposed, which for a few hours retains its darker tint.

Ridge-and-Furrow Topography in the Desert of Tumbes.

In some parts of the bad-lands which are considerably wind-worn, though not intensely stream-lined, a pronounced ridge-and-furrow (" house roof ") topography results. This occurs where the strike of the beds is along the direction of the prevalent wind.

These ridges have sharp, straight crests and flat dip-slopes, which are formed by the pebble-bands or fossil-seams. Frequently the continuous flat dip-slope of a large ridge is formed by a single seam, no more than three inches thick. The furrows are V-shaped. The ridges and furrows of each fault-block are developed independently, and terminate against the transverse fault which separates it from the next block, and which generally is marked by a transverse gully. (See Figs. 1, 86, 87.)

Stream-lined Hills in the Desert of Tumbes.

The wind-erosion has been most severe between Talara (lat. 6) and the Rio Chira (lat. -16), in the hilly ground adjoining the Salina Plains.

In the much-dissected parts of the bad-lands, groups

Photograph by C. O. Bosworth.

Fig. 88.—Wind Erosion, 2½ miles E. of Punta Parinas.

The wind is blowing from the right background towards the left, at a slight angle with the course of the valley.

Photograph by T. O. Bosworth.

Fig. 89. Wind Erosion, 2½ miles inland from Punta Parinas.

The wind is moving from the right to the left, slightly towards the foreground. The shape of the fronts of several small hills is seen in profile.

Photograph by T. O. Bosworth.

Fig. 90.—The etched front of a hill, at the edge of the Salina Plain, 2½ miles E.S.E. of Punta Parinas.

The front is facing to the right, from whence comes the wind The position of the summit, over the front, is well seen

Photograph by T. O. Bosworth.

Fig. 91.—Sand-worn gully, trending steeply up the front and over the top of a hill mass, facing the wind, at the edge of the Salina Plains, 2½ miles E.S.E. of Punta Parinas.

View taken looking northwards.

of hills more or less "stream-lined" are the rule. But it is among the hills near, or bordering on, the Salinas that the most advanced stages of the wind-erosion are seen.

These much-worn hills tend to have blunt, rounded fronts, facing the wind. Hundreds of these fronts may be seen when looking north-east from the Salina Plains.

The "front" is steep and smooth, and the summit of the hill is over it. (Figs. 88, 89.) Even when blowing strongly, the wind has little force upon it. In some instances little channels, etched upon these fronts during rains which occurred long ago, are still preserved. (Fig. 90.)

In some places the process of development of the fronts may be observed. Here there are wind-cut gullies running steeply up the windward end of the hill-mass, which are actively engaged in dissecting it into proper fronts. These smooth U-shaped gullies, up which the sand is driving fiercely, may pass right up the hill and over it, retaining their full width to the top, and carving out the right path for the air currents, almost regardless of the strike of the rocks. (Fig. 91.)

On the top of the stream-lined hill there is a sharp crest or "keel," following the direction of the wind. This may be straight or curved, according to the arrangement of the air currents necessitated by the surrounding hills. The "keel" has its highest point at the summit, which is over the front end of the hill. From that point onwards the "keel" gets gradually lower, until it becomes a mere "tail" behind the hill. (Figs. 92, 93, 95, 96.)

Some of these " tails " are hundreds of yards long. They may be partly built up of blown sand. The tails are not perfectly straight but may have slight bends and turns. They occur on the smallest objects as well as on large hills. The tail steers the hill through the air, with minimum loss of energy; just as the tail of a fish, or the rudder of a boat, facilitates its movement when not travelling directly with the current.

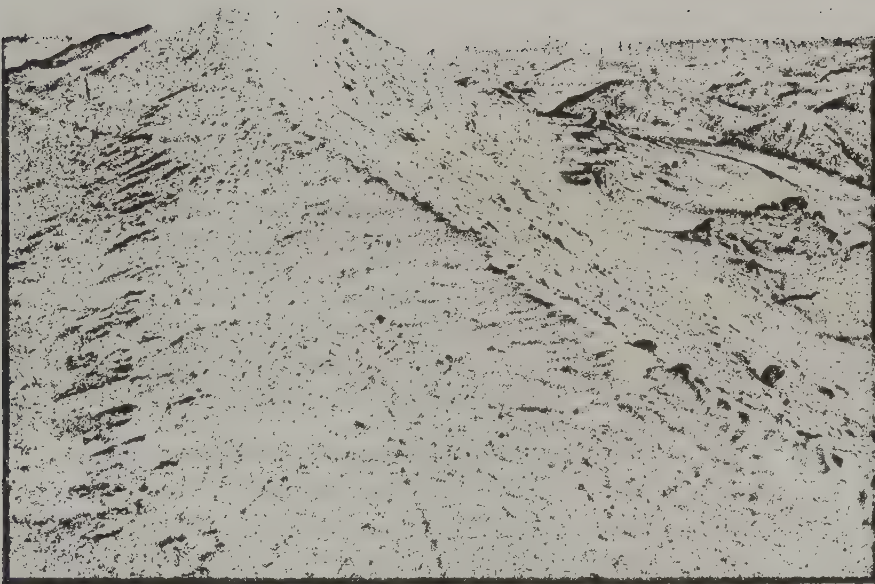
The last stages in wind erosion are seen in the low ground around the inland border of the Salinas. From parts of this ground the hills have been totally erased, but, here and there, isolated little hills occur which have attained almost the ideal windform. These hills all possess south-west orientation, facing the prevalent wind. (Figs. 94, 95, 96, 97.)

The examples which approach perfection are few and small—20 feet high or less. They are smooth all over, and possess a rounded, blunt front, a rounded summit, and a slight keel which passes into a low, straight tail.

There is a tendency for all other objects in the desert, besides the hills and the dunes, to adopt this advantageous shape. Stunted bushes of *Algarroba*, *Zapote*, and *Bechia* frequently grow to this pattern; whilst the lizard, which is the chief animal inhabitant, also has partially acquired it,—as previously did the great land reptiles which frequented the Mesozoic deserts.

WIND DEPOSITS.

No accumulations of an enduring character have been formed in the Desert of Tumbes, other than the breccias which were deposited by water.



Photograph by T O Bosworth.

FIG. 92.—View of a Wind-cut Hill, from the back, showing part of the tail, the keel, and the summit. (1 mile south of Negritos.)

Photograph by T. O. Bosworth.

FIG. 93.—View of a Wind-cut Hill showing summit, keel, and tail. (1 mile south of Negritos.)

In the right background the Salina is seen, with some salt upon it.

Photograph by T. O. Bosworth.

Fig. 94.—A Windform Hill, 4 miles S.E. of Punta Pariñas.

The wind is moving from left to right.

Photograph by T. O. Bosworth.

Fig. 95.—A Windform Hill, near Lagunitas.

Wind blowing from right to left.

Photograph by T. O. Bosworth.

FIG. 96.—Two Windform Hills, 1½ mile E. of Punta Parinas.

The wind is moving directly towards the observer.
(The shape of the larger hill has been slightly marred by quarrying a little material for the railway embankment.)

Photograph by T. O. Bosworth.

Fig. 97. Front of a Stream-lined Hill, 5 miles E. of Punta Parinas.

Wind is blowing from a little to the left of the observer. The beds are clay-shales of the Lobitos Formation. A "sandstone dyke" is seen in the foreground.

There are many dunes of several kinds, which will be described below; and the majority of these are permanent so long as the climate and the topography are unchanged. But when the next subsidence and marine transgression occurs, these deposits will be destroyed.

Sandstorms sweep the desert daily during the winter, commencing in April. The territory most affected is the southern half of the desert, from Talara to Payta. The severity of the storm is according to the strength of the wind. At times it continues all day, and the view is so obscured that it is difficult to see anything 50 or 100 feet away.

"Remolinos," several hundred feet in height, are common in the winter, especially on the tablazos. Sometimes three or four of them, one behind another, were observed travelling at 30 or 40 miles an hour.

Part of the blown sand is derived from the sea-shore. It is picked up by the south-west wind, on the 20 miles of low coast-line, south of Punta Parinas, which faces the full force of the wind. Eventually some of this sand is swept into the sea again, farther northward, where the coast-line has a north-east trend.

The sand dunes in this desert may be grouped into four main classes:

1. Coastal dunes.
2. Attached dunes.
3. Windform dunes.
4. Crescentic dunes.

Coastal Dunes.

Along a considerable part of the desert coast there is a prominent belt of coastal dunes. They occur next to the beach, separating the Salinas from the sea. The largest mass extends south-eastward from Punta Parinas to the Rio Chira; and another large body of them borders the coast north of Mancora.

The large coastal dune belt, south of Punta Parinas, has an unbroken length of twenty-two miles, with a width varying from ½ to 1½ miles, and a height of 30-40 feet.

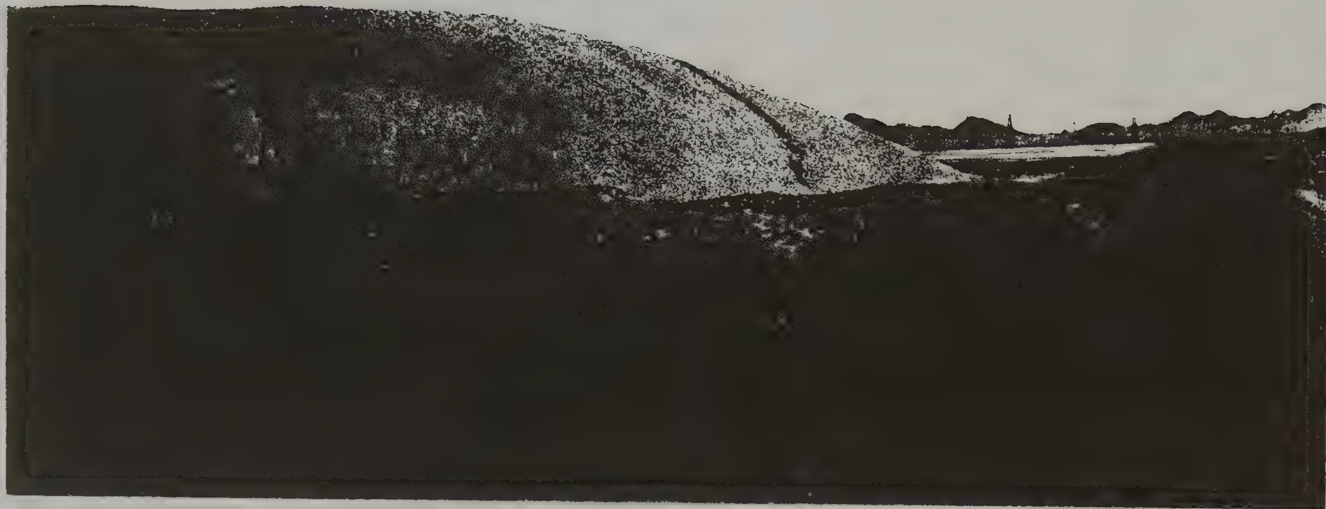
It consists mainly of a long, continuous, double-topped ridge having two parallel rounded crests, together with an irregular mass of lesser dunes which are grouped on either side of the main ridge. The majority of the more separated dunes, on the landward side of the belt, are of windform shape. (Fig. 105.) Part of these coastal dunes consist largely of shells—particularly the valves of two species of pelecypods, one of which is two or three inches in length. (Fig. 98.)

The coastal dunes are stationary, though it is possible that the width of the belt is being gradually augmented.

Attached Dunes.

This class of dunes is found in all parts of the desert. These are the drifts of sand which the wind adds or attaches to the obstacles in its path, to make their shape less resistant.

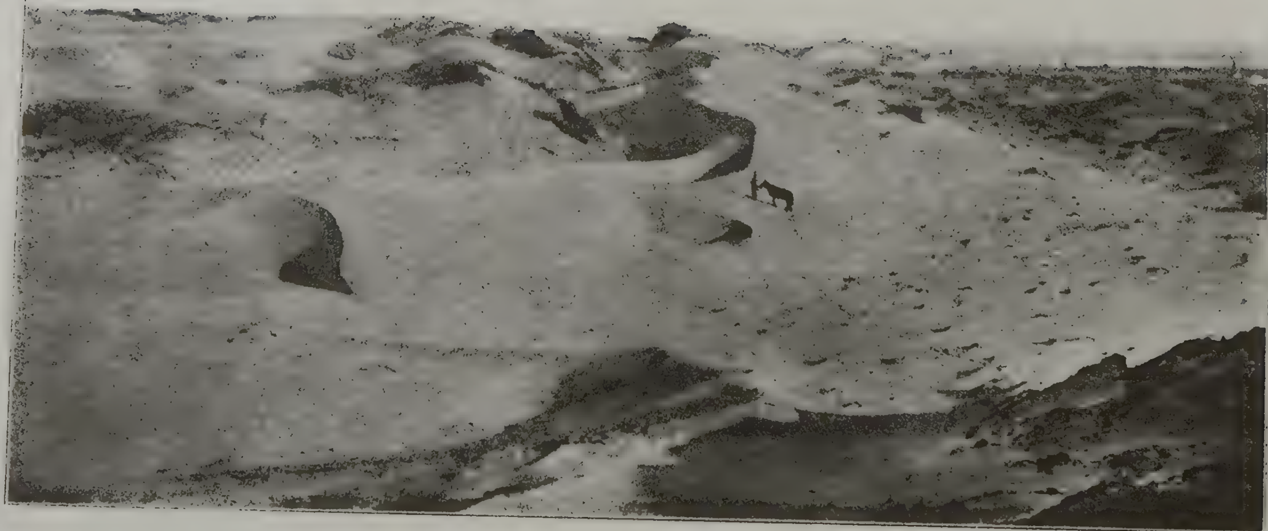
Behind any irregular rock there are dead-air spaces in which circulating currents are produced, caused by friction with the passing wind, and which themselves



Photograph by T. O. Bosworth.

Fig. 98.—Dune formed of large shells, at inland edge of the Coastal Dunes, a few miles south-east of Punta Parinas.

Wind ripples are seen in foreground on a smaller dune of sand.



Photograph by T. O. Bosworth.

FIG. 99. Tail Dune behind a hill, about 6 miles inland from Punta Parinas.

The wind is blowing towards the observer.

cause wake currents in the air stream that is passing by. By the infilling of these dead-air spaces with blown sand this loss of energy is avoided, or, in other words, the hill is given stream-line form and so makes less resistance to the wind.

These attached dunes are adjusted to the dead-air space as exactly as gravitation will allow. In many cases the sand, with the support of the air currents, is lying at angles steeper than the angle of rest.

Blown sand is ever drifting along the slopes of these dunes, seeking for a resting-place but finding none. It is not possible to add a handful anywhere, and if a handful is taken away it is very soon replaced.

On account of gravitation, however, it is impossible for some of the dead-air spaces to be filled up with sand completely. Unfilled dead-air spaces often can be found, and they can be tested by throwing up little pieces of paper—which are seen to move around in circular currents instead of passing on with the wind. Thus the attached dunes can only bring the hill to perfect stream-line form in parts. Some of these parts, however, especially the "tail dunes," appear to be complete.

The attached dunes around a group of hills are of many and varied shapes, a few of which can be specified. Many are so large that they were mapped in the course of the survey. Their shapes are slightly altered from time to time according to changes in the intensity of the wind, and slight variations in its direction.

Tail Dunes are found behind the hills, and are seen in great numbers. Some are 20 or 30 feet high: the longest one noticed had a length of half a mile.

Some are almost straight, whilst others are curved, or wavy, or irregular. (See Figs. 99, 101, 102, 103.) As with the tails of the stream-lined hills, their business is to steer the hills advantageously through the wind.

Flanking Dunes, emanating from the sides of hills, are very irregular. Some of these are due to the wake currents in the passing wind. (See Fig. 104.)

Advance Dunes occur in front of steep objects such as buildings, but are less common in front of hills

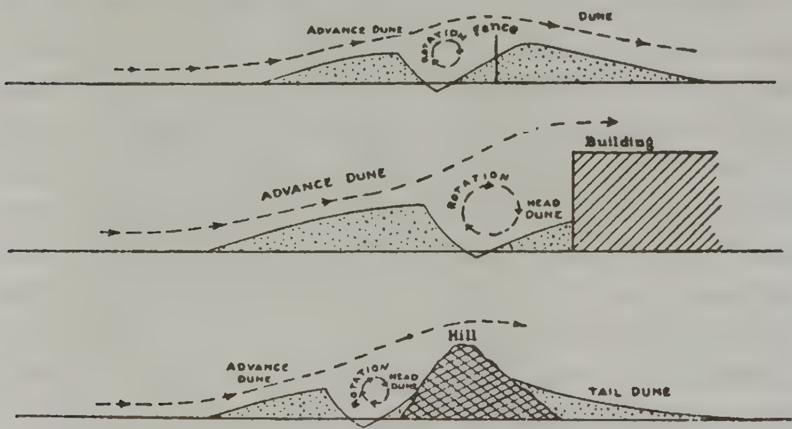


FIG. 100.—Diagram to illustrate the formation of Advance Dunes.

because these are less perpendicular. (See Figs. 100, 102, 104.)

Since the wind-stream cannot turn sharply upwards, it commences to rise at some distance in advance, and thus rides over a large body of air in front of the obstacle. In this air a rotary current is induced, which operates like a fixed wheel.

The dune occupies a dead-air space in front of the rotation, and under the rising stream. Its purpose is to facilitate the operation of the currents. Being stream-lined to them, it offers less resistance than would dead air.

Photograph by T. O Bosworth.

Fig. 101.—Tail Dune behind a hill, 2 miles east from Punta Parinas.

The wind is blowing from the left background towards the right foreground.

Photograph by T. O. Bosworth.

Fig. 103.—Valley dammed by a tail dune, 50 feet high. (Locality 1 mile N.E. of Negritos.)

The wind is from the left towards the right background.

The wind-stream ascends on the gentle front slope of the dune, and then rolls onward and upward over the rotation current, thus surmounting the obstacle with minimum expenditure of energy.

Precisely similar to the advance dune, in form and character, is the little accumulation of sand which gathers in front of any small obstacle on the bed of a stream of water.

In the case of the advance dune, the hollow in which the rotation current revolves, is the counterpart of the water wave which travels in front of a ship. This is evident on inverting the diagram, Fig. 101,—the rock now representing the ship, and the air now being replaced by sea.

The different varieties of attached dunes often are beautifully illustrated on a small scale. Overleaf is a rough sketch, showing the deposition of sand around a stone which was lying on the floor of a gully, up which a wind from the S.S.W. was blowing. (Fig. 104.)

The front of the stone (quartzite) was brightly polished, and had undergone some erosion. The blown sand was drifted around it, bringing the obstacle to stream-line form. In front there was a well-formed advance dune, followed by a frontal hollow; and a small frontal dune was attached to the stone. Behind the stone was a tail dune, which died out in the distance, and was followed by a long but gentle furrow. On either side there was a distinct lateral dune which continued far behind the stone, marking the wake currents. The arrangement of the ripples on these dunes was of symmetrical design.

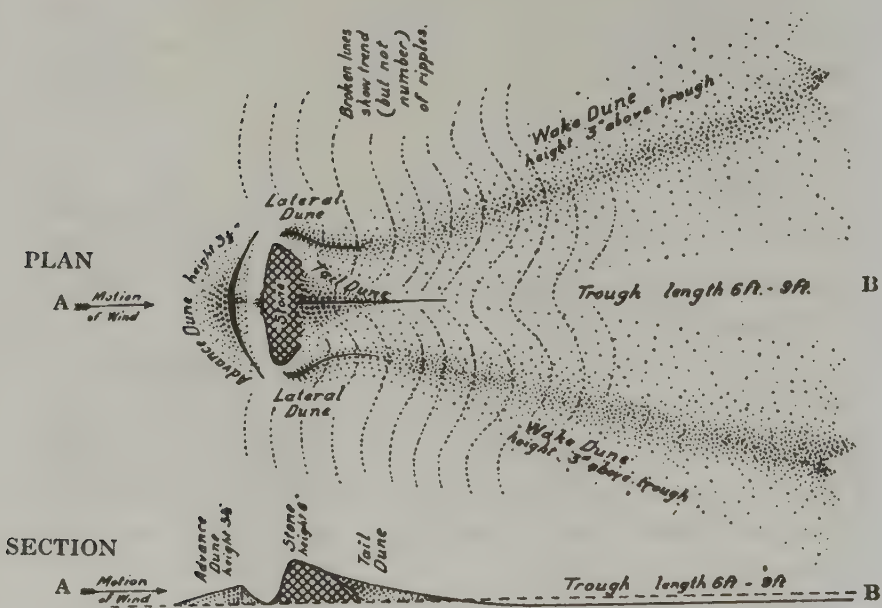


FIG. 104.—Diagram-sketch, showing Attached Dunes around a small object. The object was a stone lying on the desert floor, and having a height of 6 inches.

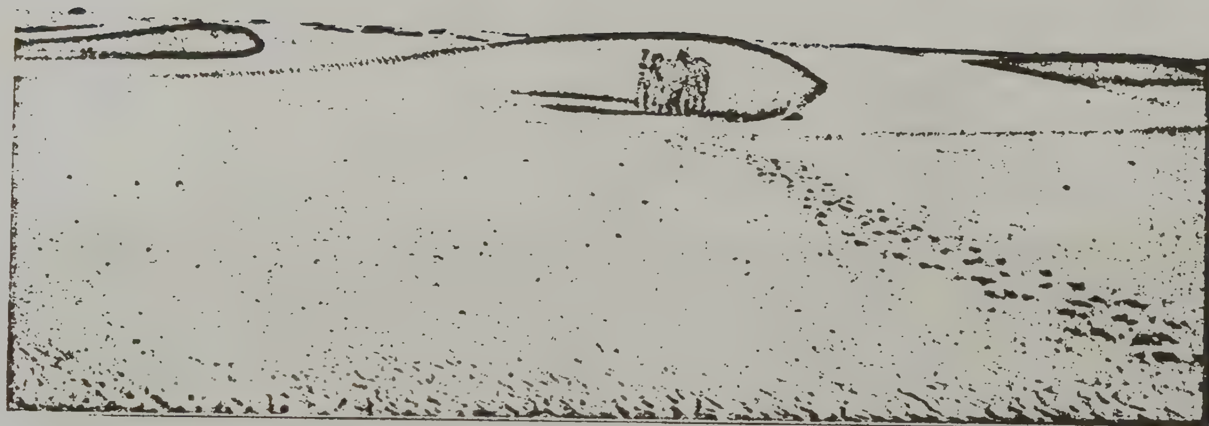
WINDFORM DUNES.

This is the most common kind of sand dune. It is a mound of sand having, more or less perfectly, the windform shape. (See Figs. 97, 98, 108.) They occur in thousands in this desert. Some areas on the tablazos are decorated with swarms of them, as also are some parts of the Salina plains; whilst small groups and individuals can be seen in almost all parts of the desert.

These dunes are stationary. They only change shape a trifle, from time to time, to adjust themselves to the variations in the wind. They are situated at irregular intervals apart, and are not placed in rows or columns. But all of them lie parallel, with their fronts facing the wind.

Photograph by O. D. Boggs.

FIG. 105.—A Windform Dune, with vegetation; on the landward side of the belt of Coastal Dunes, south-east of Punta Parinas.



Photograph by T. O. Bosworth.

Fig. 106.—Small Crescentic Dunes, on the Mancora Tablazo, south of the Rio Chira.

These dunes are never due to mere deposition by the wind for the purpose of lightening its load. In all cases they are initiated by some object in the path of the wind, around which the dune has been built up, creating the windform shape. The size varies according to the size of the object. Some are 20 feet high or more; large numbers measure 5 or 10 feet; whilst there are countless numbers which are only 2 or 3 feet high.

The obstacle in most cases was a shrub, bush, or small tree. The abundance of these dunes is a consequence of the peculiar climate. After a flood year many trees spring up and thrive for a number of years. But as the country dries up, the ground becomes bare and sandy, and the young tree becomes a stunted bush; soon, blown sand drifts around it, and accumulates in the dead-air space behind, thus building up a windform dune. Later, when the tree dies, the dune may long remain; for being of windform shape, it offers very little resistance to the wind.

Within some of these dunes, at their heads, stunted trees are still alive. On the front of others, especially near the sea, matted desert creeping plants are growing.

In some places, where the stunted trees have perished, there are large groups of these dunes in process of decay. Shifting winds, or some physical change in the surroundings, have put them slightly out of harmony with the air current, and they are now being eroded away.

Crescentic Dunes.

These are the only moving dunes in the desert. They occur in many places, but are less numerous

than the kinds described above. Evidently they are the result of particular conditions which pertain only to special localities.

Usually there are several, or a number of, crescentic dunes together. All have the same orientation, and there is some tendency for them to occur in columns, and sometimes almost in a row.

A large group occurs on the tablazo, west of Piura; and also south of the Rio Chira (elevation about 250 feet). (Fig. 106.) On the Salina Plain there are a number of them a few miles north of the Rio Chira, and again around the mouth of the Quebrada Ancha and within it. (See Fig. 107.)

Where crescentic dunes occur on the bare flat tablazo surface, it is conspicuous that, in between the dunes, this stony surface often is as clean and free from sand as if it had been swept.

These crescentic dunes in Peru are similar to those of other deserts,—described as burkhans, barchanes, medanos,[1] etc.

The largest crescentic dune observed had a height of about 40 feet, and the smallest about 2 feet; but the majority are 5-25 feet high.

The accompanying contoured plan shows a crescentic dune, measuring 17½ feet, seen near the mouth of Quebrada Ancha. The plan is from a rough field-map, made with the help of a hand level. (Fig. 107.)

Such explanations for crescentic dunes as have hitherto been formulated, appear to the author

[1] Vaughan Cornish, various papers. J. Walther, *Gesetz der Wustenbildung in Gegenwart und Vorzeit*, Berlin, 1900.

inadequate. And in particular, the view[1] that the crescentic is merely a modification of the common dune (windform) due to shortage of sand, is un-

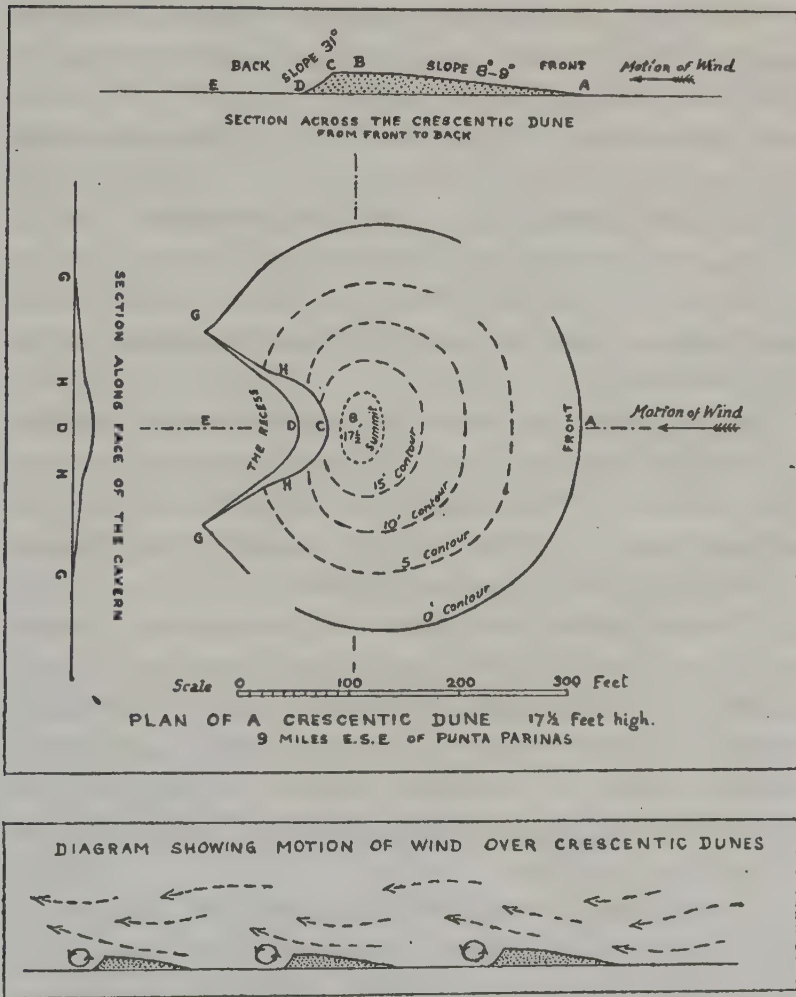


FIG. 107.

acceptable. The shape of the crescentic is so totally unlike the windform, that some different explanation must be sought.

[1] R. D. Oldham, *Memoirs Geol. Surv. India*, vol. xxxiv. part iii.

Like other dunes, the crescentic is an infilling of a dead-air space. It closely resembles the "advance dune," and is of rather similar origin.

It is thought that the crescentic dunes are formed only in places where it is necessary for the wind to ride over a body of air—which likewise is the case with the advance dune. All the special places where the crescentic dunes were found, accorded with this idea. Thus, often they were found a short distance in front of the foot of a plateau or hill mass. Here, is the place where the wind must have commenced to rise, and is overriding a body of air which lies before the cliff.

Again, they were found a little way back from the Salina Plains, on the floors of wide quebradas cut in the tablazos. Here the wind sweeps inland over the tablazo, and overrides the air which is imprisoned within the walls of the quebrada.

Especially they were found, on the tablazos, within a belt a short distance back from their vertical sea-cliffs. Here the wind from the sea rises steeply, two or three hundred feet, to clear the cliffs; and before it can regain a horizontal course on the land, it overrides the air on the tablazo for some distance back from the edge.

In all these cases, rotary currents are induced in the body of air which is overriden by the wind. These, acting like fixed wheels, facilitate the motion of the wind-stream over them.

The crescentic dune is merely a mound of sand deposited in the dead-air space in front of the rotation and under the rising wind-stream.

This infilling with sand is advantageous to the

working of the currents; for, were the space occupied by air, there would be much waste of energy due to the interference of conflicting counter-currents. But on the front slope of the solid dune the wind-stream can more easily commence its upward overriding movement; whilst behind the solid dune, in the recess, the rotary current can perform with much less friction.

All these motions of the air are achieved with minimum resistance, since the crescentic dune is stream-lined to this system of currents.

The onward march of the dune is operated by gravity. The shape of the dead-air space, pertaining to the most advantageous disposition of the currents, happens to have a back slope steeper than 31° (which is approximately the "angle of rest" for sand); and probably it has an overhanging crest. Thus the sand is ever striving to build a form which it is unable to retain. As fast as the air-stream brings grains forward to the appointed place, gravitation draws them down the steep slope; and so the dune moves onward.

CHAPTER V

ANIMAL AND VEGETABLE LIFE IN THE DESERT

The Desert of Tumbes is a treacherous habitation for animal and for vegetable life. For a year or two after the occasional floods, which occur perhaps twice in a century, there is moisture in the ground for plants, and herbage for beasts. But from then onwards, conditions increase in severity, until most of the living things have perished. Dried-up water-holes and decayed huts indicate the places where humans have struggled on until conditions became impossible for them.

The valley of the Rio Chira contains villages with a total population of several thousand; as likewise do the valleys of the Rio Tumbes and Rio Piura (which are to northward and to southward of the territory here particularly discussed). Also in the north part of the desert, beyond the Quebrada Mancora, there are a few small villages built around water-holes.

On the coast, the town of Payta receives its water supply by pipe line, whilst the several petroleum mining settlements use either distilled sea-water, or else water imported by ship.

The place where the Spaniards, under Pizarro, first landed in Peru, is near Tumbes. After taking

Photograph by R. G. Sammons, 1920.

Fig. 108.—*Algarroba* trees, with fruit, in Quebrada Parinas.

Photograph by A. H. Lee.

Fig. 109.—"*Rabo de Leon*," growing among blocks of quartzite, in the Amotape Mountains.

(The height of these plants here is about 3 feet.)

the village of Tumbes, they marched up the valley to the edge of the mountains, and then crossed the desert southward to the Rio Chira. Here they took the village of Amotape and proceeded down the valley to the sea. Stories picturing this territory as a land of plenty, with well-built towns, rich with gold and emeralds, are probably in error. The present villages are built of sticks and mud; and there are no stone foundations of older habitations, such as are plentiful in Ecuador.

In a number of places, however, there are shell mounds marking the burial grounds of a prehistoric race. These contain old pottery and occasionally primitive beads of stone and shell, and rarely, small gold or copper ornaments. The pottery is said to indicate a pre-Inca civilisation, some six centuries older than the time of the "conquest."

In the mountains a few deer are found and there are ground squirrels, called "ardeo." In the plains there are foxes; and occasionally puma, and also skunk are seen. Lizards are present in large numbers; and there are a few coral snakes. A number of birds live where there are bushes, including a small species of humming-bird, and also doves, hawks, and buzzards. Condors, from the Andes, come for dead horses or burros. In the mountains there are flocks of green parrots and parrakeets.

VEGETATION IN THE DESERT.—The amount of vegetation in the desert is very small, but has varied widely from time to time. After the flood of 1891 there were green bushes and flowering plants in many

places, where now there are but a few dead sticks. At present there is less vegetation than at any time that is remembered.

Travelling straight inland from Punta Parinas (lat. 0) to the mountains, several kinds of vegetation are encountered.

In the Salinas and the Bad-lands there is practically nothing growing, with the exception of some juicy creeping plants on the fronts of some of the coastal dunes, which perhaps obtain moisture from the slight mist that is formed along the shore, in the evening.

A few miles inland, on the floors of some of the quebradas, there are stunted shrubs of *Algarroba* and *Zapote*, and in some places bushes of "*Rhealingo*" and *Bechia*.

The *Algarroba*[1] is the most important plant in the region (Fig. 108). Its bean-like fruit, borne twice a year, is the main crop in this part of Peru. This is the principal fodder for horses, mules, burros, and goats. The wood, which is extremely hard, is used for railroad-ties, etc., and also is burnt for charcoal. (Fig. 62 and Fig. 63.) The *Algarroba*, in the valleys of the Rio Chira and Rio Tumbes, is a large tree; but in the desert it is a stunted shrub. It is protected to some extent by thorns and by the bitter taste of its leaves.

The *Zapote* also is eaten by animals when in the desert. It has a large seed-pod which is a food of the foxes. (Fig. 110.)

The "*Rhealingo*" and the *Bechia* are not edible.

[1] *Prosopis alba* (Griseb.)?

Photograph by T. O. Bosworth.

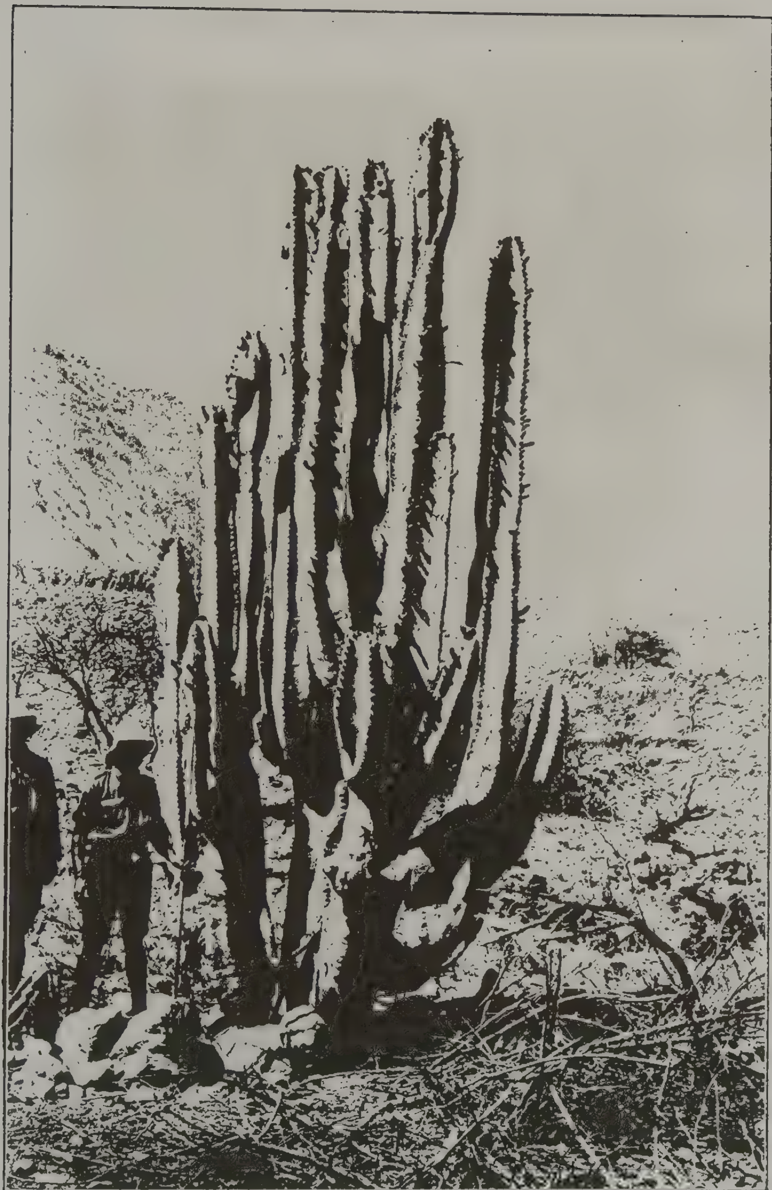
Fig. 110.—On the Breccia Cone, near the Amotape Mountains, looking north-eastwards.

In the foreground, a *Zapote* bush, and the tree-cactus *Cardo*.

Photograph kindly lent by Mr. Beeby Thompson.

FIG. 111.—A *Zapote* tree, in Quebrada Tucillal, north of Zorritos.

A tree cactus, *Cardo*, is seen in the left background.



Photograph by T. O Bosworth.

Fig. 112.—The cactus "*Gigante*," on a terrace in Quebrada del Muerto, in the Amotape Mountains.

Photograph by T. O. Bosworth.

Fig. 113.—Vegetation in the Amotape Mountains,—at altitude about 2800 feet.

On the right, "*Prickly Pear*" (*Opuntia* sp.), "*Gigante*" (*Cereus* [illegible]), and "*Cardo*." In the centre, in front of the Author, "*Rabo de Leon*" (*Pilocereus* ? sp.) On the left, a tree, bearing "*Spanish Moss*" (*Tillandsia usneoides*?), and "*Tupeia*" (*Puya* ? sp.)

Approaching the mountains, there is more moisture in the ground, underneath the watercourses; and in places a variety of plants are growing on the floors of the quebradas.

At an elevation of 600-800 feet, just outside the mountains, we pass a few specimens of the branching tree-cactus "*Cardo*," which farther northwards becomes very numerous.

After entering the mountains, we find in the valleys, well-developed *Algarroba* trees, the gum tree *Bualtaco*, and one or two others.

On ascending farther to an elevation of, say 1500 feet, and thence onwards, we find the giant cactus "*Gigante*"[1] growing in profusion on every slope. (Fig. 112.) This cactus throws up a group of vertical columns to a height of 20 or 30 feet. This is the principal tree on the mountains, and from a distance of several miles, every hill appears to be bristling with these spires. (Fig. 60.) The "*Gigante*" is so brittle that, if pushed with sufficient strength, it snaps off sharply and goes crashing down the mountain side. It is rather soft; and, with a machete, it can be slashed into pieces. These pieces are surprisingly heavy. The inside is juicy, and is eaten by thirsty animals.

In this zone, occupied by the "*Gigante*" and a number of smaller species of cacti, the *Algarroba*, *Zapote*, "*Rhealingo*," and *Bechia* have entirely disappeared. There are, however, one or two other small trees which bear little or no foliage, but are clad with flowering parasites (or more properly,

[1] *Cereus* sp. (*C. peruvianus?*).

epiphytes), clustered thickly about the outer and upper parts of the boughs and branches.

The most noticeable of these is a stunted form of the "*Palo Santo*,"[1] growing to a height of 15-20 feet. Any part of this tree, on being bruised or scratched, gives out a penetrating odour rather like peppermint. When burnt, it makes a fragrant smoke. (It is said that it is used locally for incense.) Mules and burros will eat small quantities of this tree.

The most valuable growth in the mountains is the parasite (epiphyte) known as "*Tupeia*,"[2] which is the only plentiful substance upon which the beasts can live. The "*Tupeia*" consists of a bundle of long juicy leaves, which have the shape of hyacinth leaves but are larger, and a spire of purple, sweet-smelling flowers. This plant grows abundantly on every tree or bush, in the upper parts of the mountains, at say about 2000 feet. (Figs. 60 and 115.)

Here there is also a bright yellow orchid, which grows in large clusters on many of the trees. Occasionally the author's mules and burros,—20 or 30 of them,—were fed entirely with this plant. On the high summits, about 3000 feet, there are a few dwarfed trees, thickly draped with "Spanish Moss."[3] (Fig. 113.)

The chief problem facing the plant life is that of getting water. In this business the parasites (epiphytes) support the host, for at night they extract a remarkable amount of water from the cloud of mist which enshrouds the mountain tops. So much do they obtain

[1] *Porliera* sp.

[2] A *Bromeliad*, perhaps of the genus *Puya*.

[3] *Tillandsia usneoides?*

Photograph by T. O. Bosworth.

Fig. 114.—"*Spanish Moss*," on stunted trees, on a summit in the Amotape Mountains. Altitude about 3500 feet.

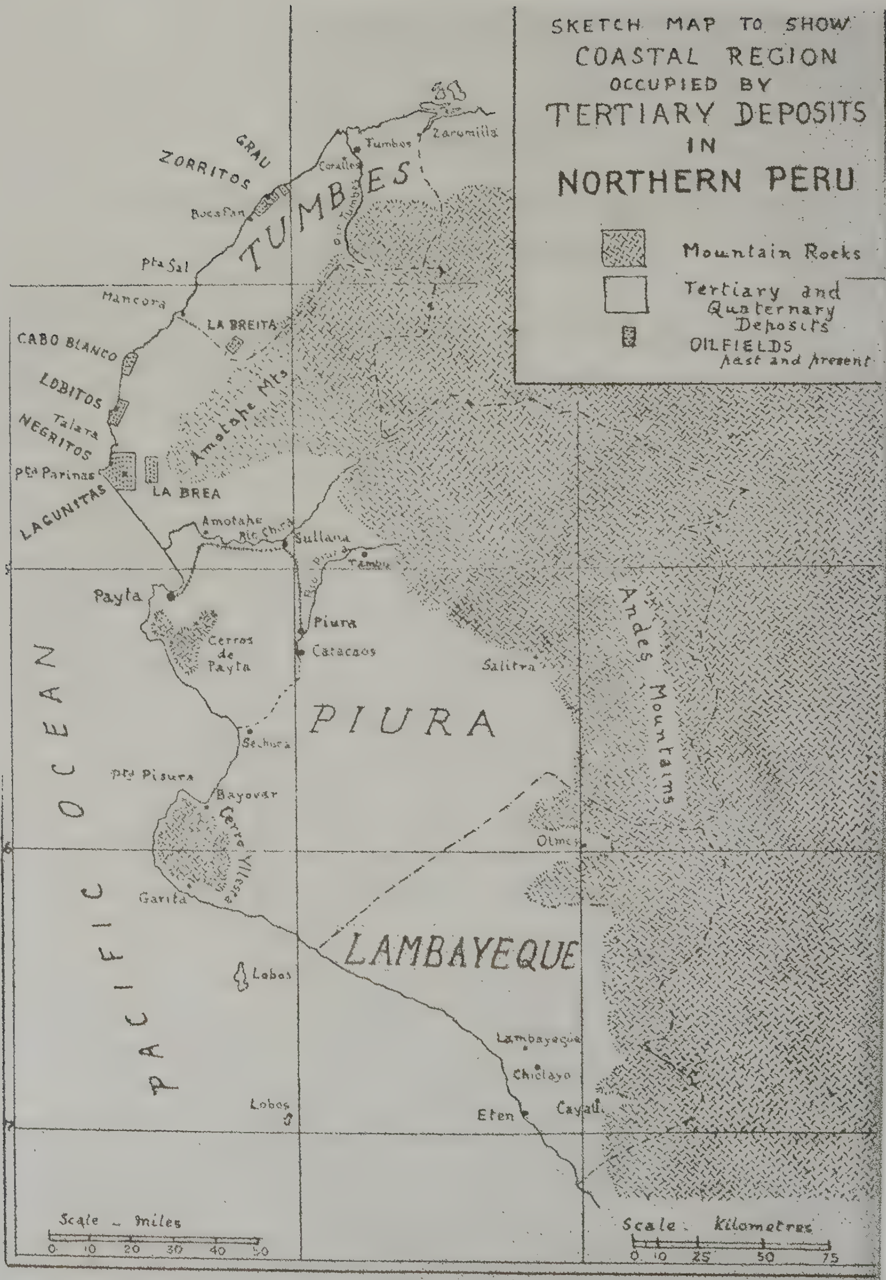
that the water drips off from them all night, like a light shower, upon the ground beneath, thus feeding the roots of the tree.

The zonal distribution of the vegetation, which is suggested in the foregoing remarks, is only roughly in accordance with altitudes. It is more truly a distribution according to the supply of moisture. The moisture increases as the mountains are ascended—and also it increases towards the north part of the desert. Thus the various plants, mentioned above, are found at lower elevations as we proceed northwards. For instance, the line of "*Cardo*" trees approaches gradually nearer to the coast; until at Cardalitos, 25 miles north-east of Mancora, and thence northward, it is abundant along the seaside. The *Bualtaco* also, and the "*Palo Santo,*" occur near sea-level at the north end of the desert. The "*Gigante,*" found at 1500 feet in the mountains east of Punta Parinas, is seen occasionally near the sea at Cabo Blanco, on the Mancora Tablazo, at an elevation of 900 feet.

PART V

PETROLEUM IN THE LITTORAL REGION OF NORTHERN PERU

By T. O. Bosworth, D.Sc., M.A.



SKETCH MAP TO SHOW COASTAL REGION OCCUPIED BY TERTIARY DEPOSITS IN NORTHERN PERU
Mountain Rocks
Tertiary and Quaternary Deposits
OILFIELDS past and present
TUMBES
PIURA
LAMBAYEQUE
PACIFIC OCEAN
Andes Mountains
Amotape Mts
GRAU
ZORRITOS
Tumbes
Zarumilla
Corrales
Bocapan
Pta Sal
Mancora
LA BREITA
CABO BLANCO
LOBITOS
Talara
NEGRITOS
Pta Parinas
LA BREA
LAGUNITAS
Amotape
Rio Chira
Sullana
Tambo
Payta
Piura
Catacaos
Cerros de Payta
Salitra
Sechura
Pta Pisura
Bayovar
Cerro Illescas
Olmos
Garita
Lobos
Lambayeque
Chiclayo
Eten
Cayalti
Scale – miles
0 10 20 30 40 50
Scale Kilometres
0 10 25 50 75

FIG. 116.

CHAPTER I

SUMMARY OF THE MAIN FACTS IN THE GEOLOGY OF THE REGION

In the preceding parts of this volume, the geology of the Littoral has been set forth at some length. In this chapter the chief facts which have been established are briefly re-stated, for readers who are interested mainly in the oil.

The Littoral.

The petroleum, in this part of Northern Peru, occurs in a strip of country generally less than 20 miles wide, bordering the Pacific Ocean. (Fig. 116.)

The Littoral is a desert region, comprising salt-marshes (" salinas "), " bad-lands," plateaus (" tablazos "), and rugged hills generally less than 1000 feet in height. All of these are composed of soft sedimentary rocks of Tertiary and Quaternary age, such as clay-shales (" greda "), sandstones, pebble-beds, and shelly limestones.

At the inland boundary of the Littoral, lie the outermost ranges of the Andes, which are formed of much harder and much older rocks.

The Outer Ranges of the Andes.

The outer Andean Ranges, which border the Littoral in the petroliferous region, are (proceeding from north to south) the Amotape Mountains; the

mountains around Cerro Ereo; and the mountains behind Piura. Also there are the isolated mountain masses known as the Cerros de Payta, and Cerro Yllesca, which project up through the Tertiary deposits of the Littoral and are surrounded by them.

In these mountains the principal rocks are hard slates and quartzites, with intrusions of granite, dolerite, etc. There are also some rocks of Carboniferous (?), Jurassic, and Cretaceous age.

The rocks of the outer ranges had been tilted, folded, and carved into mountains, before the Tertiary Period commenced.

No indications of petroleum have been found within these mountains.

Petroleum confined to the Tertiary of the Littoral.

In the Littoral, outside of the mountains, the rocks exposed consist of a great thickness of Tertiary beds, capped by a thin cover of Quaternary sediments.

The former Pacific Sea, in which these deposits were formed, extended over the present Littoral to the foot of the Amotape Mountains. Its shore-line was along the mountain flanks. The mountains of Payta and Cerro Yllesca were mountainous islands in this ocean.

The Tertiary deposits consist mainly of clay-shales, with bands of sandstone and occasional beds of conglomerate. An interesting feature is the presence of very frequent thin seams of beach-pebbles and shells.

The total thickness of these Tertiary beds is at least 15,000-20,000 feet; all of which is of shallow-water origin, and obviously was formed not very far from shore.

Evidently a great subsidence movement was in progress, and this large thickness of shallow-water sediments was accumulated on a subsiding continental shelf.

It is not known what lies immediately underneath the Tertiary deposits. No boring has yet passed through them into any older formation, except in a few instances, at places within 2½ miles of the mountains,—in which cases, the mountain slates and quartzites have been reached.

It is in the Tertiary rocks only, that the oil is found.

Structure in the Tertiary Formation.

There are no anticlines in the Littoral. The structure in this oil region is very different from the structures common in most other oilfields.

Here the earth's crust has been broken up into innumerable independent blocks,—somewhat like a shattered thick sheet of ice.

The main blocks are separated from one another by large faults, which have displacements often amounting to several thousand feet.

These fault-blocks still stand in their own places, though they have been tilted in various different directions and have undergone different vertical movements, so that some have sunk down whilst others have been upraised.

In many cases there has been much crushing of rocks along the fault-planes; and in some instances the crush-belts are ¼ mile, or more, in width.

The main fault-blocks are of all sizes, some of the larger ones measuring two or three miles across; but the greater number are quite small

and could be measured in thousands, or hundreds, of feet.

The large fault-blocks generally are further broken up by a network of smaller faults.

Apparently the faulting was wholly post-Tertiary; and the main fault-blocks originally all contained the whole series of Tertiary strata, 15,000-20,000 feet thick.

But the subsequent and contemporaneous erosion — by wave, wind, and flood — has denuded them variously, so that some now only contain the lower members of the Tertiary Formation, whilst in others much higher beds are still retained.

Thus each block differs from every other block, not only in having different strike and dip, but also in having different strata exposed to view at the surface. (See geological maps in Part I.)

The Quaternary Formations.

The Quaternary deposits, though occupying about three-fourths of the surface, are more conspicuous than important. They are only a "blanket formation," and are barren of oil.

From a scientific viewpoint, however, the Quaternary deposits are very interesting. They have been discussed at length in Part III. Here, only a brief statement is needful.

After the block-faulting and denudation of the Tertiary deposits already mentioned, the whole land surface has been subjected to "up and down" movement, which is still in progress.

This has caused several invasions, and subsequent retreats, of the sea. The deposits made by the sea on these occasions are the "tablazo beds," which have

Photograph by T. O. Bosworth.

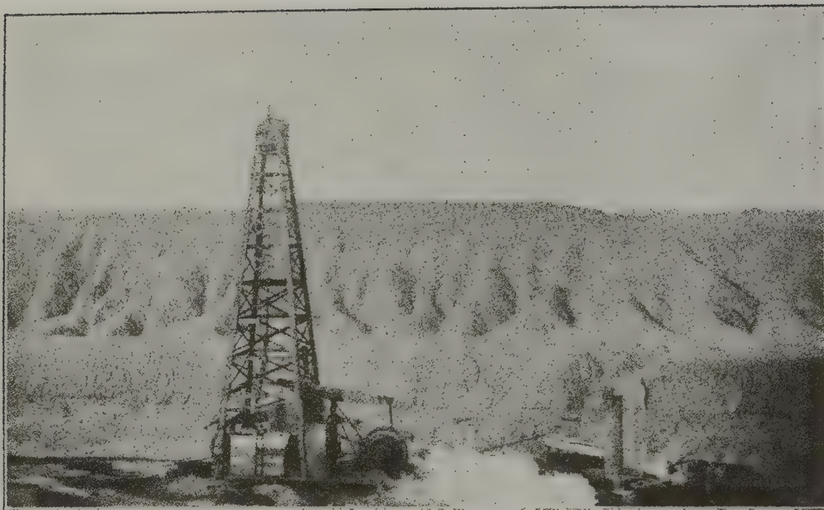
Fig. 117.—Geological Survey Work in the Oilfield Regions. Dr. Bosworth's survey party moving camp in the Amotape Mountains.

This photograph was taken on the granite mountain mass, Cerro Buenos Aires, about 3000 feet above sea-level. The parasitic plants on the trees are "*Tupeia*" and *Orchids*; the mules and the burros were fed with these

Photograph by T. O. Bosworth.

Fig. 118.—Geological Survey Work in the Oilfield Regions. Dr. Bosworth's survey party moving camp in the Amotape Mountains

This photograph was taken on the granite mountain mass, Cerro Buenos Aires, about 3000 feet above sea-level The parasitic plants on the trees are "*Tupeia*" and *Orchids*; the mules and burros were fed with these



Photograph by A. H. Low, 1920.

Fig. 119.—In the Negritos Oilfield, Well No. 954, east of Negritos on the outcrop of the Turritella Series.

Behind the derrick, the Turritella beds are seen to be dipping away from the observer at an angle of about 25°

Fig. 120.—Determining position of a place on the trail across the great Salina, midway between Negritos and the Rio Chira.

From right to left—Mr. W. Light, Don Julio Seminario (in white), the late Mr Evans, with field-glass, (then Manager of Oilfield), Dr Bosworth (at plane table), Mr. T. Scott (subsequently Manager at Lobitos)

covered practically the whole of the Littoral, almost to the mountains, and almost completely concealed the Tertiary rocks.

The chief of these Quaternary deposits are :

Lobitos Tablazo Bed	10	feet thick.
Talara Tablazo Bed . . .	20	,, ,,
Mancora Tablazo Bed . .	250	,, ,,

A succession of uplift movements have brought these sea-floor deposits up above sea-level, so that they now occur in the form of extensive marine terraces, known in Peru as "tablazos" (tablelands). The sea-shells in the deposits are all of living species, and the uplifts are still continuing. Thus, geologically speaking, these Quaternary beds are of very recent age—though the time which has passed during the process of their production almost certainly must be measured in tens of millions of years.

The oldest marine terrace is the Mancora Tablazo, which in the Cabo Blanco district has attained an elevation of 1000 feet. This bed covers a large part of the map, extending from Quebrada Mancora southward to Payta, and beyond. The elevation and thickness, however, decrease to southward, until at Payta the bed is only 50 feet thick, and its surface is 200 feet above sea.

The Talara Tablazo occupies a large area around Talara, and inland from Negritos. It has an elevation ranging from 280 feet, near Talara, down to 150 feet or less, as we approach the Rio Chira.

The Lobitos Tablazo occurs only as rather small remnants of a former extensive plateau. It occupies small areas along the coast between Cabo Blanco and Punta Parinas, having elevation of 120 to 60 feet.

Erosion and denudation of the tablazo beds has taken place extensively along the coast, and along the flood-water courses, and also in wind-swept areas. In those places where the covering of tablazo beds has been removed, the Tertiary rocks beneath are now exposed to view. But about three-quarters of the Littoral is still covered over by the tablazo beds.

Salinas, which are sandy plains and salt-marshes, just above sea-level, occupy large areas along the coast. They are ground from which the sea has withdrawn in comparatively recent times, and are the result of an uplift movement which is even now in progress. The salinas are discussed in Part IV.

A great Breccia Fan, about 100 feet thick, consisting of stones washed down from the mountains, covers a large area along the inland border of the Littoral. This is a desert deposit which extends over the tablazos and also over ground in which the Tertiary rocks would otherwise be exposed. In the La Brea oilfield, for instance, which is situated on the Breccia Fan, the oil has seeped up to the surface from outcrops of Tertiary rocks which are underneath the breccia deposit.

The Stratigraphy of the Tertiary Formations.

The Tertiary rocks extend from the sea to the mountains, occupying an area of about 3000 square miles, within the territory here studied, and indicated on our map (Folder No. I.).

But in only about one-fourth of this area have these rocks been exposed to view, by denudation of the Quaternary deposits; and even in the ground from which the tablazo beds have been eroded away, the Tertiary rocks are largely concealed by desert sand.

The Tertiary of the Littoral can be divided into three main formations, as follows :

3. Zorritos Formation, 5000 feet (?)

(*c*) Sandy Series.
  Several hundred feet thick.
  Mainly sandstones and conglomerates.
  Many fossils.

(*b*) Passage Series.
  Some hundreds of feet thick.
  Clay-shales with some beds of sandstone.

(*a*) Shale Series.
  Large thickness of clay-shales.

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2. Lobitos Formation, 5000 feet (?)

There are two different facies of this formation.

(*A*) In the south, the formation consists essentially of clay-shales almost devoid of fossils, with occasional bands of gritty sandstone. The lowest thousand feet of the formation, however, is composed of clay-shales with many beds of pebbly sandstone, and fossil-bands.

(*B*) In the north (commencing near Talara), the formation consists of clay-shales, with many bands of yellowish calcareous sandstone containing nummulites.

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1. Negritos Formation, 7000 feet +

(*b*) Clavilithes Series.
  "Parinas Sandstone," 1000 feet.
    Sandstone, conglomerate, with some beds of clay-shale.
  "Shales with Pebble-Seams," 3000 feet.
    Clay-shales with many beds of sandstone, and seams of beach-pebbles and fossils.

(*a*) Turritella Series.
  "Shales with Pebble-Seams," 1500 feet.
    Clay-shales with many beds of sandstone, and seams of beach-pebbles and fossils.
  "Shales unexposed," 1500 feet.
    Clay-shales, etc., probably similar to those above, but known only in borings. Arbitrarily divided from beds above, at horizon of the "Main Oilsand."

The formations, tabulated above, have been discussed in some detail in Part I. of this book, where geological maps also are included; whilst the fossil contents have been described in Part II. But the presence of the petroleum in the rocks was not dealt with in those pages.

The **Zorritos Formation** is of Miocene age, as indicated by its fossils. There is probably an unconformity between these beds and the Lobitos Formation beneath,—but no contact or junction has been seen. The Zorritos Formation is exposed extensively in the north part of the region, north of the Quebrada Mancora. It was but little studied by the author.

On this formation, stand the Zorritos oilfield and the oilwells of Quebrada Heath.

The **Lobitos Formation** is of Eocene age. Its fossils are wholly different from those of the Zorritos Formation, above. These deposits occupy a large part of the region, in the middle and south part of our map.

The Lobitos oilfield stands on rocks belonging to the northern facies of the formation; whilst part of the Negritos oilfield, particularly the plot which used to be known as the Lagunitas oilfield, stands on beds belonging to the southern facies.

The **Negritos Formation** is of Lower Eocene age. There is a conformable junction between this and the Lobitos Formation above. These rocks are exposed only in several comparatively small areas; notably—at Cabo Blanco; near Corral Quemado (Jabonillal); around Negritos; near La Brea; and near Bayovar.

The Cabo Blanco (Restin) oilfield, and a large part of the oilfield of Negritos, and also the oilfield at La Brea, stand on beds of the Negritos Formation.

Throughout the greater part of this large pile of Tertiary sediments, the evidences of petroleum are found. Productive oil-sands are being exploited, at intervals, almost from the bottom to the top. The oil-sands and their distribution will be further considered in Chapter V.

CHAPTER II

THE SURFACE INDICATIONS OF PETROLEUM

Rocks have Petroleum Odour.

The presence of petroleum in the Tertiary rocks is evident to the sense of smell, at the outcrops of the productive formations.

In the Negritos Formation, around Negritos, for instance, practically every outcropping sandstone seam smells of petroleum. Often the odour is clearly perceptible without digging or breaking the rock for it. Many of these oil-sands are not quite white on their weathered surface, but have a peculiar pinkish tint. The clay-shales of the Negritos Formation, many of which are rich in small carbonaceous particles, also smell strongly of petroleum.

In the Lobitos Formation, some of the gritty sandstones in the southern facies smell of oil. This is notably the case in the sandstones north-east of Lagunitas.

In the northern facies some bands of calcareous sandstone contain the petroleum odour; but generally it is rather faint, and some digging and rock-breaking are needful before it is plainly perceived.

In the Zorritos Formation, parts of the sandy series smell strongly of petroleum.

Oil on the Sea.

Oil on the surface of the sea, on this part of the Peruvian coast, is often noticeable both from the cliffs and from on board ship. The presence of the petroleum causes large patches of smooth, "oily," water, which are particularly conspicuous when the surface of the sea is rippled or slightly rough. They are well seen opposite Cabo Blanco and Punta Restin, and between Talara and Punta Parinas.

"Mud Volcanoes."

Mud-springs, with oil and gas issuing from them, occur in a few places in this region, but are not numerous.

The largest mud-volcano is the one known as "El Volcan," 1 mile N.N.W. of the old workings at La Brea, and 12 miles inland east of Negritos (lat. 2, long. 14). (See Fig. 121.) It stands on the great Breccia Fan, at a distance of 2 miles from the foot of the mountains. The rocks beneath the breccia, which give rise to the seepages, belong to the Negritos Formation.

This "volcan" consists chiefly of one main mud-cone, 10 feet high, measuring 20 feet by 30 feet across. It has an old crater, 10 feet in diameter, containing 2 small active vents inside it. There is also another active vent outside, at a distance of 50 feet from the centre of the main cone. From each of these apertures there issue a small flow of muddy water, and a little oil and gas.

Other "mud-volcanoes" (?) occur in the north part of the region, 5½ miles south of Zorritos, 2 miles inland,

on the south bank of the Zapotal valley, which is a branch of the Quebrada Boca Pan.

The mud springs here, are known as "los hervideras" ("the boilers"). It is said that they exude some oil, as well as the hot salt water, mud, and gas, which are more plainly in evidence. The rocks underneath these springs probably belong to the thick series of clay-shale of the Zorritos Formation.

Oil Seepages.

Ordinary seepages of oil are numerous in this territory.

In the north they occur at Zorritos, Quebrada Heath, Quebrada Tucillal, etc., arising from rocks belonging to the upper part of the Zorritos Formation.

At La Breita, inland 14 miles E.S.E. from Mancora, there are deposits of brea which have been worked for centuries, and which are the residues of copious seepages of rather heavy oil. The brea at this place is mingled with superficial gravel.

In Quebrada Siches, a branch of Quebrada Amarillo, 4 miles south of Cabo Blanco, and 4 miles inland, pools of oil occur which are said to replenish themselves. Here the oil oozes out of a sandstone bed which probably belongs to the Negritos Formation.

Near Jabonillal, inland 7 miles from Punta Capullana (lat. 11, long. 10), there are seepages arising from rocks belonging to the Negritos Formation, which are faulted up at this place.

In the Mogollon District, 13 miles inland, E.N.E. from Talara (lat. 10, long. 17, etc.), there are numerous seepages in Quebrada del Viejo, Quebrada Mogollon

Photograph by T. O. Bosworth.

Fig. 121.—"El Volcan," a mud-volcano, 1 mile N.N.W. of La Brea. The cone is about 10 feet in height and 20×30 feet across.

This view, looking westward, shows the author working at a plane table, on the summit of the cone.

Photograph by T. O. Bosworth, 1916

FIG. 122.—Oil Seepage on the Salina, 4 miles S.E. of Negritos, near the oilwells of "Section 38."

This picture shows a dark mound, consisting of brea and desert sand, which has been carved and shaped by wind erosion. The wind blows from the right foreground towards the left background.

and Quebrada Salado, which are tributaries of Quebrada Parinas. These seepages, which are within 3 miles of the mountains, arise from beds in the Clavilithes Series of the Negritos Formation.

At La Brea, 13½ miles inland, almost due east from Punta Parinas, there are extensive brea deposits, which are the residue of large seepages of rather heavy oil. This place, which is 2 miles distant from the foot of the mountains (lat. 1, long. 13½), was the scene of the principal brea workings of ancient times. There are several other seepages in the same neighbourhood. Here the oil issues from sandstones in the Turritella Series of the Negritos Formation, which are buried under some 10 feet of stones belonging to the great Breccia Fan. The oil comes up through the breccia, to the surface.

At and around Negritos there are numerous seepages; notably those south of the village, and 1½ mile E.N.E. of Punta Parinas, where large brea-pits were worked in ancient times. Other seepages occur on the Salinas, south-east of Punta Parinas, at distances of from 1 mile to 2¾ miles. All of these arise from sandstone seams in the Negritos Formation.

A little farther southward, however (lat. 2½, long. 3½), there are seepages on the Salina, which probably come up from the Parinas Sandstone member of the Negritos Formation or else from beds in the Lobitos Formation. Here the oil has mingled with the surface sand of the Salina, making black sandy mounds. These are eroded and furrowed by the wind into curious shapes (Fig. 122).

Around Lagunitas (lat. −2, long. 4½) there are a

number of seepages, arising from sandstone seams in the southern facies of the Lobitos Formation.

In the Pozo Valley (lat. 1, long. 5), 3 miles north of Lagunitas, and 4 miles east of Negritos, there are seepages among crushed rocks, and also in the desert sand. It is uncertain whether the beds from which these seepages arise belong to the Negritos or to the Lobitos Formation.

In the Bayovar district, and around Cerro Yllesca in several localities, there are seepages of oil which are believed to issue from rocks of the Negritos Formation. Thus in the Salina de Bayovar it is reported that oil occurs in a pool containing mud and salt crystals. At Reventazon, near the south-east corner of these mountains, and also at La Garita near their south-west corner, seepages of oil are known.

In the Lobos Islands, 40 miles south of Bayovar, there are large seepages and old brea-pits.

"Puff Sand."

In places, the colour of the desert sand is darkened owing to the presence of a small percentage of oil in it. The substance which gives this brown stain to the sand, is the residue left by light oil, or oil vapour, on passing through the sand to escape into the air.

Often this sand, to a depth of several inches or a foot, is perfectly dry and is lying very loosely and lightly on the surface. On walking or riding through the sand, it puthers up like a thick cloud of heavy dust. The odour of the oil is then very noticeable. It seems probable that the condition of the "puff sand" is due to oil vapour and gas rising through the sand, to the surface.

These puff sands occur in many places, notably around the outcrops of oil-sands of the Negritos Formation at Negritos, and west of La Brea.

(Photographs were taken to show the puthering puff sand, but unfortunately they were not successful.)

Gas Springs.

Although undoubtedly much gas is issuing out of the rocks and up from the ground, the gas seepages are not a conspicuous feature of these oilfields. This is due to the absence of pools or springs of water, wherein the uprising gas might manifest itself.

In the few mud-springs, already mentioned, gas is seen, bubbling up. The odour of petroleum arising from the rocks is further evidence of escaping gas, as also are the puff sands mentioned above.

Sulphur.

In many places, especially on the Salinas around Negritos and Lagunitas, crystals of sulphur occur in the oil-soaked ground. Often, for instance, on turning over a slab of weathered shale, an odour of oil comes up from below, and a quantity of yellow sulphur crystals are seen on the underneath side of the slab or lump. Then on digging down a little farther, an oil-sand, or even some brea or heavy oil, is found.

Sulphur is frequently found, also, on the surface of the exposed shales and sandstone beds which smell of oil.

Occasionally a quantity of fine, yellow sulphur powder, together with alum, is found on the ground

covering the outcrop of an oil-sand (*e.g.* at Lagunitas, in several places). The finding of the sulphur was, in fact, generally followed up by the finding of oil.

In some instances, several pounds of sulphur could be gathered up, and some of the lumps of sulphur weighed several ounces. It is suggested that the sulphur deposits which have been mined near the oil seepages at Reventazon, south of Bayovar, likewise may be related to the oil.

The sulphur presumably is liberated by the reducing action of the petroleum hydrocarbons, on the alums, gypsum, or other sulphates which result from the desert weathering of the shales in the presence of salt water.

CHAPTER III

HISTORY OF THE OILFIELDS

THE petroleum industry has been long established in Peru; and the oilfields have grown slowly and steadily, until to-day they are producing at the rate of nearly 4,000,000 barrels per annum.

Although this output is only about ·5 per cent of the world's annual oil-supply, it entitles Peru to rank ninth among oil-producing countries.

The oilfields described in the following pages have been, up to the present time, the principal oilfields of the South American Continent.

The total quantity of oil produced in Peru up to the end of 1921 is approximately 34,000,000 barrels, being about ·3 per cent of the petroleum which the earth has yielded.

The Principal Oilfields.

The developed oilfields of Peru, with the exception of the small primitive oilfield of Pirin, in the hills near Lake Titicaca, are all situated on the Littoral, which has been described in the foregoing portions of this volume.

The present producing areas are located, at intervals, along a hundred miles of coast-line, in the Provinces of Tumbes and Payta.

In order from north to south, there are the following commercially productive fields :

1. The Zorritos oilfield, 18 miles south-westward from Tumbes.
   This field is owned by a Peruvian Company, and is operated by Italians and Peruvians. It produces about 260 barrels of oil per day ; which is 2·5 per cent of the country's output.

2. The Lobitos and Cabo Blanco (Restin) oilfield, occupying parts of the coast from Cabo Blanco southward for 17 miles, almost to Punta Capullana. This field consists of two separate and quite different portions:
   (*a*) A newer field, between Cabo Blanco and Punta Restin.
   (*b*) An older field, around Lobitos.
   A British Company, the Lobitos Oilfields, Ltd., owns and operates this oilfield. The daily production (March 1922) is about 2300 barrels, which is approximately 22·25 per cent of the output of the country.

3. The Negritos, Lagunitas, and La Brea oilfield, south of Talara, extending along the Littoral for about 4 miles on either side of Punta Parinas. This field consists of two parts, which at present are distinct :
   (*a*) The large Negritos oilfield, which occupies the extent of coast-line above mentioned, and now also stretches inland for 7 miles. This field includes also an area which once was worked by a separate Company, and was known as the Lagunitas oilfield.

(b) The La Brea field, which lies 13 miles inland from Punta Parinas, near the foot of the Amotape Mountains. At present this field is separated from the main Negritos (and Lagunitas) field by 6 miles of undeveloped territory.

This large oilfield is owned by the International Petroleum Company of Toronto, a subsidiary of the Imperial Oil Company of Canada. It is operated by Canadians, Americans, British and Peruvians.

The production is about 8000 barrels daily, which is 75 per cent of the output of Peru.

Besides these several producing oilfields, there are a number of other places at which small quantities of oil have been obtained, or at which exploitation has been attempted, such as Grau, Cardalitos, La Breita, and Bayovar, etc.

Primitive Exploitation in Ancient Times.

The exploitation of the petroleum resources by primitive means, began in Peru, as in most other oil lands, in prehistoric days.

At Negritos, La Brea, La Breita, Lobos Islands, and other localities, pits were dug into the outcrops where natural seepages occurred. The heavy oil was skimmed or bailed up from the pits, and was then heated in earthen cauldrons until a dense pitch or "pez" was produced. This substance was used for making an impervious lining to the large earthenware jars in which liquor was kept, and probably for various other waterproofing purposes. In the mortar used

for some of the ancient buildings, pitch appears to have been one of the ingredients. It was employed also in the preservation of mummies.

Development during Colonial Times.

As the earlier peoples of Peru have left us no literature, the first written accounts of oil in Peru are contained in the writings of the Spanish conquerors.

Thus Jose Acosta, a Spanish Jesuit, in his records, written about the year 1580, relates:

> "As we came sailing for New Spain along the coast of Peru, the pilot showed me the island called Lobos, where there is a spring or well of pitch or copé. This pilot, an excellent man in his profession, told me that he had come navigating here many times; and sometimes so far out at sea that he could not see land, but he knew by the odour of the bitumen, where he was, with as much certainty as if he could see land, so strong is the odour given off."

As in many other countries, in early days, the natural asphaltum was used for pitching the hulls of ships and boats.

One of the Spanish explorers, Fray Reginaldo de Lizaraga, writing of the Ecuadorian Coast, just north of Peru, makes mention of this:

> "There is, not far from here (Punta Santa Elena) a spring, from which flows a liquid-like brea, and not in small quantities, which is utilized by vessels instead of pitch as we did with ours, because when it began leaking we put into the Bay of Caraquez, rounding Cape Pasao eight leagues beyond Manta,

from where we sent the long boat with some sailors to this point for the brea, which is called 'copey,' and when it arrived the vessel was discharged and careened and painted and caulked with the brea that had been boiled down to thicken it, so that sailing from there we navigated without so much danger."

In the early days of the Spanish Conquest, the "brea" industry was actively continued. In several places around Negritos, and also especially at La Brea, there are quite extensive workings, known as the King's Brea Pits.

During Colonial rule, the minerals underneath a property did not belong to the owner of the land: for the exploitation of brea, and all other minerals in Peru, was reserved as a royal monopoly for the King of Spain. Subsequently, when the independence of Peru was declared in 1821, the mineral rights became the property of the Peruvian Government.

The monopoly of working the brea pits of Negritos, La Breà, La Breita, etc., was leased out by the Crown in return for payments of cash.

Records are preserved, of the letting of these rights, during the last century of Spanish rule, to the following operators:

Sergeant-Major Don Manuel Urdapileta and Captain Don Mateo Gonzales Sangines .	in 1709
Senor Montero Ugarte	in 1735
Don Juan Cristobal de La Cruz . . .	in 1802

The earliest precise information about these business transactions is contained in a document which was filed before the public notary in Piura, Don A. R. de las Varillas, in 1702. This states:

"Before me, the notary and witnesses appeared, Major Manuel Urdupilcta and Captain M. C. de Sanjines, and stated: that inasmuch that to-day at noon in the Public Square, at the gates of the Cabildo of this city, there was sold at auction to them for 180 pesos of eight reals, all the springs of copé or soft pitch which have been discovered or which may be discovered in the future, from the mountains of Cucus and Cerro Prieto, which run from the town and river of Amotape to the town of Tumbes, and in breadth from the seashore 30 leagues inland toward the mountains."

Cristobal de La Cruz, the last purchaser of the brea monopoly under the Spanish régime, states in his letters, that he and his forefathers had worked these mines from time immemorial. The work was continned by him until the revolutionary war.

Early History of the Oil Lands.

In the early days, the whole of the territory between Tumbes and Amotape, or in other words, between the Rio Tumbes and the Rio Chira, was known as Mancora. According to the official records this large estate was in possession of Captain Martin Alonzo Granadino, of Payta, from the year 1629, until his death.

Subsequently the property passed into the hands of Captain Juan Benito de las Heras, who married the widow of Captain Granadino. The new owner, in order to make his title doubly sure, took the precaution of purchasing the estate at public auction.

In the deeds, the boundaries are described as

> "From Amotape to Tumbes and from the springs to the sea. These barren and unoccupied lands which belonged to the king, consisting of the valleys of Parinas, Pazul, Mogollon, Quebrada Ancha, Mancora, etc., and extend from the mountains to the sea."

In 1705 the estate was given by Don Juan Benito de La Heras, to the padres of the Hospital de Belen, of Piura. More than a century later, in 1815, the property was sold by them to Don Jose de Lama.

Throughout all this time the oil rights had remained the property of the Crown, and of its successors, the Peruvian Government; and on an occasion when the Hospital de Belen applied for permission to work the brea pits, they were refused on that account.

But in 1826 the oil rights of the Mancora estate, which had been officially valued at 2695 pesos, were sold by the Government to Don Antonio de Quintana, in cancellation of a debt of 4974 pesos, which was owed by them to him.

In the following year, 1827, Quintana resold these rights to Don Jose de Lama, the owner of the surface of the estate. And thus all the main oilfields of Peru, as regards surface rights and also as regards mineral rights, then became the property of one man.

At the death of Don Jose de Lama, in 1840, the estate was divided between his heirs.

The northern part, which was still known as

Hacienda Mancora, included the present oilfields of Zorritos and Lobitos; whilst the portion south of the Quebrada Honda, which was called Hacienda La Brea y Parinas, included the present oilfields of Negritos, Lagunitas and La Brea.

The Hacienda La Brea y Parinas later passed, through purchase, into possession of the Helguero family, and became the property of Don Genaro de Helguero, in 1886. But the Hacienda Mancora remained in possession of the De Lama family, and later was subdivided among their numerous descendants.

During all this long period the exploitation of brea or pez continued. Even as recently as ten or eleven years ago, the pits at La Brea were still being worked, the product being conveyed by burros to Talara, where it was received by the London and Pacific Petroleum Company.

Oil Claims and Oil Taxes in Recent Years.

The Government appears to have recovered possession of the oil rights over parts of the Mancora estate, for a large number of "minas" have been granted along the coast, between Tumbes and the north border of the Hacienda La Brea y Parinas.

Under the Mining Code of July 6, 1900, oil-mining claims on uncultivated lands were obtainable (until 1910) from the Government, by "denouncement."

The maximum size for a concession, or "mina," was 60 "pertenencias"—the pertenencia being a square plot containing 4 hectares of land (9·88 acres).

The rental due to the Government for an oil concession is £3 per annum for each pertenencia.

Altogether, in this part of Peru, 221 concessions,

containing 7020 pertenencias, had been taken up by denouncement; and a further 45 concessions, consisting of 221 pertenencias, had been granted in other ways.

But by decree of Sept. 2, 1910, the Government prohibited the denouncement of any further oil claims, their purpose then being that the remaining oil lands should be reserved for the State.

A law (No. 2187) imposing an export tax of one shilling per metric ton on crude petroleum and its products, was made in November 1915.

The tax was increased and regulated in August 1917, by a further law (No. 2423), which made the amount of the tax proportionate to the market price, in the United States, of Pennsylvania crude.

A new Petroleum Bill was passed by the Senate in 1921, and was recently approved by the House of Deputies. This Bill, which thus becomes law, fixes the export tax at 3½ Soles (7 shillings) per ton, and provides for the further granting of oil-mining concessions, and for the encouragement of new development.

Dawn of the Petroleum Industry at Zorritos, 1860–1873.

In the brea industry, the value of the crude oil was judged according to its viscosity, and any diggings which yielded a more fluid oil, known as "pez liquido," were regarded as rather a failure.

It was not until 1860, when refined kerosene was first imported into the country, that the value of this "pez liquido" was perceived. Attempts to inaugurate a petroleum industry were forthwith begun, in 1862, by Don Diego de Lama, one of the owners of the Mancora estate. The work was commenced

near Zorritos, where inflammable oil had been met with plentifully, in digging for pez.

A number of wells were dug, and a quantity of crude oil was shipped away in barrels; but the profits were insufficient, and eventually the operations were suspended.

After this, several similar enterprises were started, but without making a commercial success.

As the cause of failure was chiefly insufficiency of capital, a company was formed in 1864, by De Lama and others, in New York; but the outbreak of the Civil War in the United States, prevented the company from undertaking the work.

In 1867 a Pennsylvanian oil operator, named Prentice, visited Peru, and subsequently drilled some of the earliest oilwells at Zorritos. The first well is said to have yielded 60 barrels a day at a depth of 146 feet. The second well, on being deepened in 1876 to 500 feet, is stated to have spouted from the 6-inch casing to a height of 70 feet. So promising were these results, that Mr. Prentice proceeded to erect a refining plant.

In 1870 exploitation in the Zorritos field was undertaken by Mr. Henry Smith, another North American; but after a considerable amount of useful development work had been done, further financial support became necessary.

At this stage Mr. F. G. Piaggio, of Callao, entered the business, becoming in 1875 a partner, and ultimately, in 1883, the owner of the property.

The Early Drilling Operations at Negritos, 1873–1875.

The Negritos district now attracted attention, as a probable petroleum field, and in 1873 extensive

prospecting was begun by Mr. Henry Meiggs, who constructed a small refining plant at Callao.

In 1874, after the death of Mr. Meiggs, who is said to have spent $150,000 on the property, the business was acquired by the firm of J. B. Mulloy and Company, of Lima, which also made arrangements for the shipment of the crude oil from the hitherto unoccupied harbour of Talara.

The field operations were managed by Mr. E. Fowkes, who drilled three wells to a depth of 330 feet, all of which were productive, the first being reported as a 400-barrel well.

Unfortunately, in the war with Chile, the installations, buildings, and machinery were destroyed by the cruiser Amazonas; and this promising enterprise came to an end.

Revival and Growth of Oil Industry at Zorritos, from 1883.

After the war, the Zorritos oil industry was the first to be revived; and in 1883 Mr. Piaggio, now the sole owner of the property, constructed a refinery at Zorritos, built a pier, and furnished his oilfield with up-to-date equipment. From that time onward, the business has flourished, under the name El Establecimiento Industrial de Petroleo de Zorritos.

Up to the present time some 340 wells have been drilled at Zorritos; and there is now a steady daily output of crude oil, amounting to 200 barrels or more. The oil is refined at Zorritos, and is marketed in Peru.

Establishment of Modern Petroleum Industry at Negritos, by the London and Pacific Petroleum Company, from 1889.

The prospects of the Negritos field now again called for attention, by reason of the success of the Zorritos field.

In 1888 the whole of the estate of La Brea y Parinas, including both its surface and its mineral rights, was purchased by Dr. Herbert W. C. Tweddle, from the owner, Don Genaro Helguero, for £18,000.

In the following year the new owner, together with Mr. William Keswick, formed the London and Pacific Petroleum Company, which forthwith proceeded to exploit the field.

The record of the first few wells is lost, but the log of Well No. 9 shows that it had a depth of 545 feet, and was completed in 1899. It is still producing oil. In the following year, 1900, the production of the field was over 200,000 barrels of oil.

A refinery was constructed at Talara, where part of the output was refined for the Peruvian and Chilean market, whilst the remainder of the crude production was sold to American refiners, and was exported to California.

This company remained in possession until 1913, up to which time they had drilled 700 wells and had developed a production of 3500 barrels a day. It is said that the amount invested in this oilfield during that period, exceeded one million pounds.

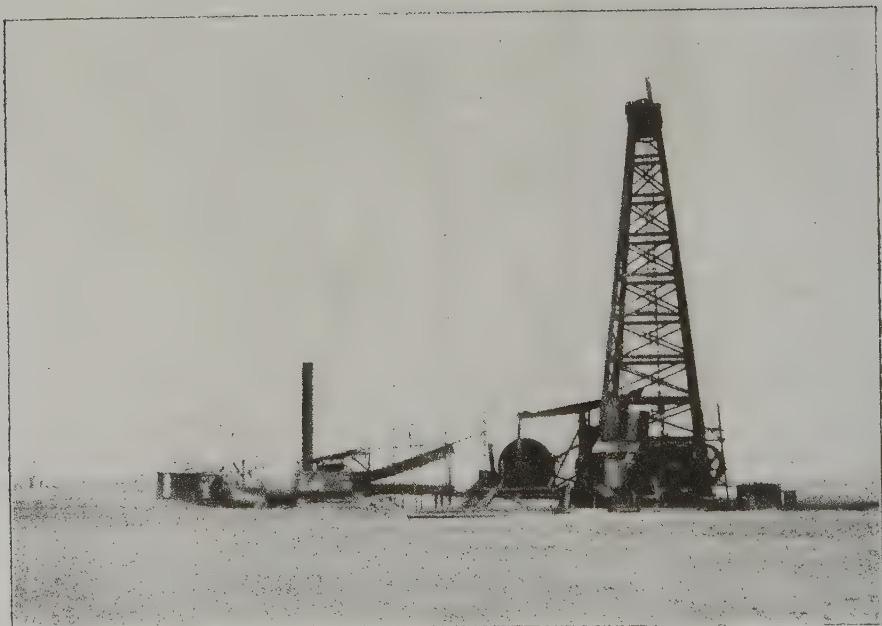
Development in Quebrada Heath, etc., by the French Company and others, 1891–1897.

In Quebrada Tucillal, inland behind the Zorritos field, oil was proved by two wells which were drilled

Photograph by T. O. Bosworth

FIG. 123.—View in the Negritos Oilfield, looking across the salt-covered Salina northward, from a point $2\frac{1}{2}$ miles south of Negritos.

The oilwells in the distance are among hills composed of rocks of the Negritos Formation.



Photograph by A. H. Low.

FIG. 124.—Drilling Well No. 960 in "Section 38" on the Salina, in 1920, 1½ miles S.E. of Negritos.

View looking north-west

in 1891–1892, by the Mancora Syndicate; but the development was not continued.

Exploitation in Quebrada Heath, 2 miles north-east of Zorritos, was begun in 1891, by the Heath Petroleum Company of London, which was formed by Don Francesco Miranda. Although oil was struck in the first well, at a depth of 830 feet, the work was abandoned.

Along the banks of this same quebrada, in 1895–1897, a number of small oilwells were obtained by a French Company, La Compagnie de Pétrole d'Amérique du Sud. A small refining plant was erected and a tank steamer was obtained; but unfortunately the yield of oil was too small, and the enterprise failed.

At La Cruz, north-east of Zorritos, a hole 1000 feet deep was drilled by the Peruvian Syndicate in 1894, but no oil was found.

South of the Oilfields—Attempted Exploitation, 1895, and since.

Near Payta, about the year 1895, Mr. E. L. Doheney carried out prospecting work. Three wells were drilled for him; but oil was not obtained.

At La Garita, and at Bayovar, near Cerro Yllesca, 46 miles south of Payta, wells were drilled in 1900 and 1912, in the vicinity of old brea pits, but no commercial production was obtained.

Discovery and Development of Lobitos Field, 1901, and since.

The discovery of the Lobitos oilfield was the outcome of prospecting work carried out by A. Milne & Company, of Callao, for the Peruvian Petroleum Syndicate in 1901. Oil was obtained at 400 feet, in the

No. 3 Well; but it was not until 1905 that oil in large quantity was proved. The Company known as the Lobitos Oilfields Ltd., which was formed in London in 1908, developed the new field with conspicuous success.

For the landing of machinery and supplies, and to facilitate the shipment of oil, a long pier was built. A condenser was constructed to produce fresh water from the sea; and soon a prosperous mining village had come into existence, on this desert shore.

The establishment of distributing depots, for fuel oil, also was commenced at various ports along the Peruvian and Chilean coasts. These, however, were taken over by the West Coast Fuel Company, which utilised them for the sale of Californian fuel oil.

For some years the output of the Lobitos field was not used in Peru, and the Company's fleet of three tankers was engaged in transporting their crude oil to refiners in California. In more recent years, however, the oil has been sold to the International Petroleum Company, and is shipped to their refineries at Talara and Vancouver.

By the year 1909 the output of this field exceeded 100 barrels a day.

Up to the end of 1921 some 375 wells had been drilled (including those at Restin); and the Company was producing 2200 barrels of oil a day.

Exploitations Inland, attempted by Taiman, 1904–1907.

Inland 2½ miles from Cabo Blanco, in Quebrada Siches, oil was obtained in 1904, in three shallow wells drilled by Mr. J. Taiman.

This ground was very difficult of access; but a road up the cliffs to the wells, was made, and plant for

condensing sea-water was installed on the shore. The development, however, was not continued.

At La Breita, 15 miles inland from Mancora, heavy oil was found in fair quantity, in 1905–1907, in a well drilled by Mr. Taiman on the site of the old brea pits. Some of the oil was conveyed to the coast in barrels, and was exported; but the undertaking proved unprofitable.

Successful Enterprise at Lagunitas, 1910-1915.

At Lagunitas, 4 miles inland east of Negritos, a plot of land measuring 4 square miles, was acquired under lease from the London and Pacific Petroleum Company in 1909, and was successfully exploited by the Lagunitas Oil Company of London.

The first well, which was completed as a 55-barrel producer, in November 1909, is still yielding 4 or 5 barrels a day.

The output of the field was piped to Talara and sold to the London and Pacific Petroleum Company.

The Lagunitas Company retained possession of the plot until 1916, by which time they had drilled about 170 wells, and had developed a production of 1400 barrels a day.

Cabo Blanco Oilfield, proved by the Lobitos Oilfields Ltd., in 1912-1913.

At Punta Restin and Cabo Blanco, 9 miles north of Lobitos, a productive area was proved by the Lobitos Oilfields Ltd., in 1912–1913, which has since been developed into an important oilfield.

At the end of 1921 some 70 wells had been drilled in this field, of which about 45 were then producing.

Unsuccessful Deep Tests between Zorritos and Mancora, 1912-1916.

The coast between the Zorritos field and the Cabo Blanco field, has been the scene of several important, but unsuccessful, tests for oil. Thus in 1912–1913, deep holes were drilled in Quebrada del Grillo and also in the Zapotal Valley, by the Lobitos Oilfields Ltd.; and in 1913–1914, two deep wells were sunk near Boca Pan, by the Boca Pan Oilfields Company, of Callao. Again in 1914–1916, two very deep tests were made by the Cardallitos Oil Company, an American concern, at Cardallitos, 23 miles north-east of Mancora; but no oil was obtained.

Purchase and Development of Negritos and Lagunitas Fields by the International Petroleum Company, 1913-1921.

The International Petroleum Company, a subsidiary of the Imperial Oil Company of Canada, purchased the oilfield and estate of the London and Pacific Petroleum Company in 1913. In 1914 they bought also a controlling interest in the Lagunitas Oil Company, and finally acquired the whole enterprise by purchase in 1916.

A vigorous development of the property has been conducted by the International Petroleum Company during the ensuing years. The producing oilfields of Negritos and Lagunitas have been much extended; and a new area of production has been opened at La Brea.

The number of wells which have been drilled in these fields is now about 1450, and the output of oil exceeds 8000 barrels a day. The buildings and installations throughout the property also have been

Photograph by A. H. Low, 1920.

FIG. 125.—Some of the ancient "brea pits" at La Brea, containing heavy oil residue.

The pits are dug down through the Breccia Fan and also through a small thickness of the Mancora Tablazo bed, and then into the Tertiary rocks. One of the new oilwells is seen in the background. The Amotape Mountains form the skyline.

Fig. 126.—Talara in 1916.

The mole is seen extending across the middle of the view. The grey building, behind it, contains the canning plant, etc. The large white building on the hill is the Club-house. The lighthouse is seen on the summit.

Photograph by T. O. Bosworth.

Fig. 127.—Lagunitas, $4\frac{1}{2}$ miles S.E. from Negritos.

This view was taken looking north-eastward towards the house of the Manager of the Lagunitas Oil Company, in 1913.

much increased. A splendid harbour at Talara has been made, with new wharves and a fine concrete mole; and a water pipe-line from the Rio Chira to Negritos has been built. The refinery at Talara has been reconstructed and enlarged to a capacity of 7000 barrels of crude per day; and there is tank storage for 1,000,000 barrels of oil.

Part of the output of these fields is refined and sold in South America, and the remainder is shipped to the Imperial Oil Company's refineries in Canada, and to other refineries in North America.

CHAPTER IV

BRIEF DESCRIPTION OF THE OILFIELDS

In this chapter brief notice will be made of the various exploitations for oil in this region,—considering them in order, as we travel from Tumbes southward along the Littoral.

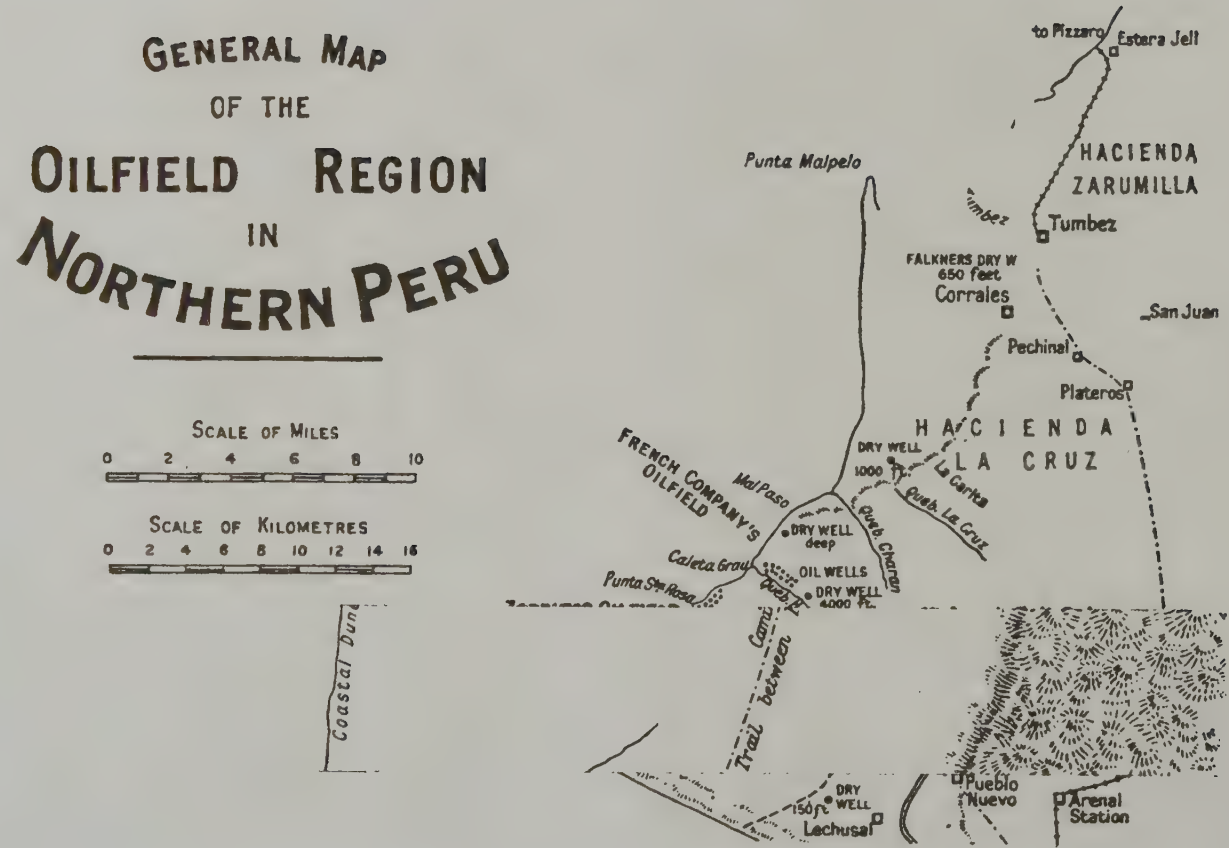
TUMBES

Near the little town of Tumbes, at a distance of about 1½ miles southward from the river, two wells were drilled, a number of years ago, by a Mr. Falkner. These holes, which were situated on either side of a quebrada, went down to a depth of 650 feet, without result.

LA CRUZ

Some 5 miles north-eastward of Zorritos at a place called La Cruz, which is near to the "landing-place of Pizarro," a well was drilled by the Peruvian Syndicate in 1894. This unsuccessful well had a depth of 1000 feet.

On the coast, not far from the cliffs of Mal Paso, 3½ miles north-east from Zorritos and within about 1½ miles of Caleta Grau, a moderately deep test well was drilled by Mr. Piaggio,—which also was without success.


GENERAL MAP
OF THE
OILFIELD REGION
IN
NORTHERN PERU
SCALE OF MILES
0 2 4 6 8 10
SCALE OF KILOMETRES
0 2 4 6 8 10 12 14 16
Coastal Dun
to Pizzaro
Estera Jell
HACIENDA
ZARUMILLA
Tumbez
Punta Malpelo
FALKNERS DRY W
650 feet
Corrales
San Juan
Pechinal
Plateros
HACIENDA
LA CRUZ
DRY WELL
1000 ft.
La Carita
Queb. La Cruz
Queb. Charan
FRENCH COMPANY'S
OILFIELD
Mal Paso
DRY WELL
deep
Caleta Grau
OIL WELLS
Punta Sta Rosa
DRY WELL
4000 ft.
Trail between
DRY
WELL
150 ft.
Lechusal
Pueblo
Nuevo
Arenal
Station

CALETA GRAU AND QUEBRADA HEATH

Heath Petroleum Company.

The inlet of Caleta Grau, and the valley entering it,—known as Quebrada Heath,—have been the scene of some interesting operations. The Caleta is situated 13 miles south-westward from Tumbes, and about 2 miles north-east from the Zorritos pier.

The development at this locality was commenced by the Heath Petroleum Company, formed in London by Don Francisco Miranda, in 1891. Two wells were sunk upon the oil claim "Abhiron," which is a long narrow strip of land comprising the floor of Quebrada Heath. One of these holes had a depth of 830 feet. Both wells encountered oil; but for lack of capital, the work was discontinued.

The French Company.

La Compagnie de Pétrole d'Amérique du Sud acquired oil claims on either side of Abhiron, and in 1895–1897 they drilled a number of wells, and were producing a small amount of oil.

A distillation plant, of daily capacity 315 barrels, was erected near the beach. A tank steamer, the *Madelina* (2400 tons), and another smaller boat, were obtained; and a storage tank was built at Callao. But the total output of the Company, during the brief period of its activity, amounted only to 830 barrels of oil.

Some 26 wells were drilled, of which 14 yielded small quantities of oil. A number of these holes were drilled by hand, 15 of them being less than 330 feet deep.

Some of the old wells, with tripods over them, can still be seen along the banks of the quebrada, about 1 mile inland from the coast.

Although the Company ceased operations within two years, the field is not quite abandoned, for one of the Frenchmen remained behind and has operated one of the old wells, generally called the Frenchman's Well, to this day.

This well, which is 280 feet deep, stands on the top of a protruding cliff of terrace, about 50 feet high. Photographs of it were taken by the author in 1913, and again in 1916. (See Fig. 128.)

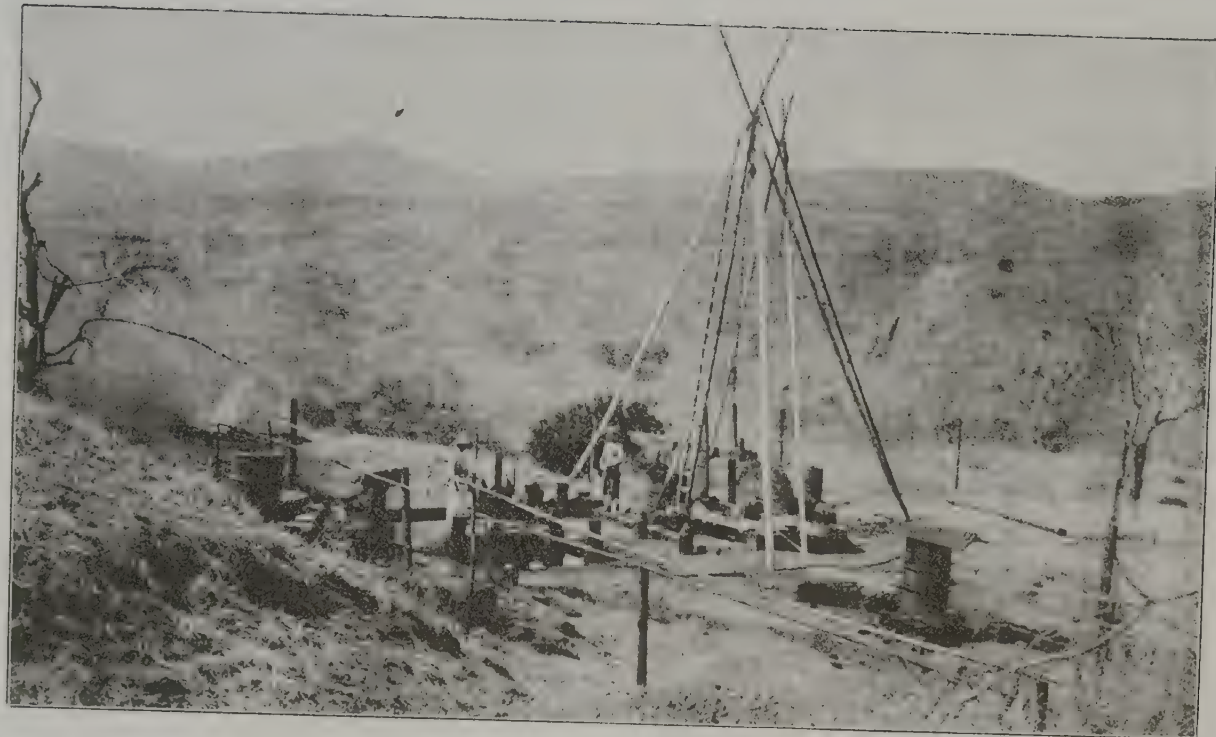
The oil is drawn from the well by a pump, which is worked by a beam operated by a treadle. The oil is then distilled in a small retort, erected beside the well, and the kerosene is condensed by passing the vapour through a length of iron pipe.

In this rude refinery the gasoline is evaporated away, whilst a serviceable kerosene is obtained, which is run into old oil cans. The residual oil is used as fuel for heating the retort.

The refined product is sold to the few natives who live near by, at a price somewhat below that at which they could obtain ordinary kerosene. Apparently the great oil corporations have spared this small competitor, who has thus successfully undersold them in this little corner of the world's market for many years.

The rocks in Caleta Grau and Quebrada Heath belong to the Zorritos Formation. (See Figs. 23, 24, in Part I.) The fault-blocks are inclined generally towards the coast, at small angles of dip.

In the neighbourhood of the wells, the cliffs of the quebrada show the sandstones which are the upper



Photograph by T. O. Bosworth.

FIG. 128.—"The Frenchman's Well" on the north bank of Quebrada Heath, north of Zorritos.

This well, which was drilled by La Compagnie de Petrole d'Amerique de Sud in 1895-97, has since been operated for many years by one of the former employees of the Company, who settled at this place. The pump which raises the oil is worked by a beam and treadle. This view shows the refinery in action. The condenser is the long pipe in the foreground. A pit of residual oil, used as fuel, is seen in front of the well. The valley immediately behind the well is Quebrada Heath.

member of the formation. The wells start on these rocks, and produce from the passage beds of alternating sandstones and shales, immediately beneath. But after going down 200 or 300 feet, the drill enters a thick series of barren clay-shales. These barren shales also are exposed in some of the cliffs, and are well seen farther up the quebrada.

In the wells, oil-sands were found only at small depth, none being encountered beyond 625 feet. The deepest test was that made by Well No. 3, which, after obtaining fairly good results between 200 and 400 feet, was then continued down to 1200 feet without finding any further production.

Deep Well of the Lobitos Oilfields Ltd.

Farther up the Quebrada Heath, about 1¾ miles from the sea, on the right bank of the valley, a deep test well was drilled by the Lobitos Oilfields Limited, in 1913–1914.

This well, which was situated on the barren shale series, went down to 4000 feet, without success. A small showing of oil was found near the top; but at depth, there was only gas and a flow of hot salt water.

ZORRITOS

The important oilfield of Zorritos, owned by the Establecimiento Industrial de Petroleo de Zorritos, has been commercially productive for about forty years.

It is said that the earliest wells were drilled by a Mr. Prentice of Pennsylvania, who first visited Peru in 1867. The Well No. 1, at a depth of only 146 feet, is reported to have yielded 60 barrels a day; and Well

No. 2, on being deepened to 500 feet, in the year 1876, is stated to have spouted to a height of 70 feet out of the 6-inch casing.

Development of the Zorritos field on a larger scale was commenced in 1870, by a North American named Henry Smith, who drilled a number of productive wells. Into this business, Mr. F. G. Piaggio entered as a partner, in 1875, eventually becoming the owner of the property.

Through shortage of capital, and in consequence of the depression caused by the Chilean War, the growth of this business was checked for several years.

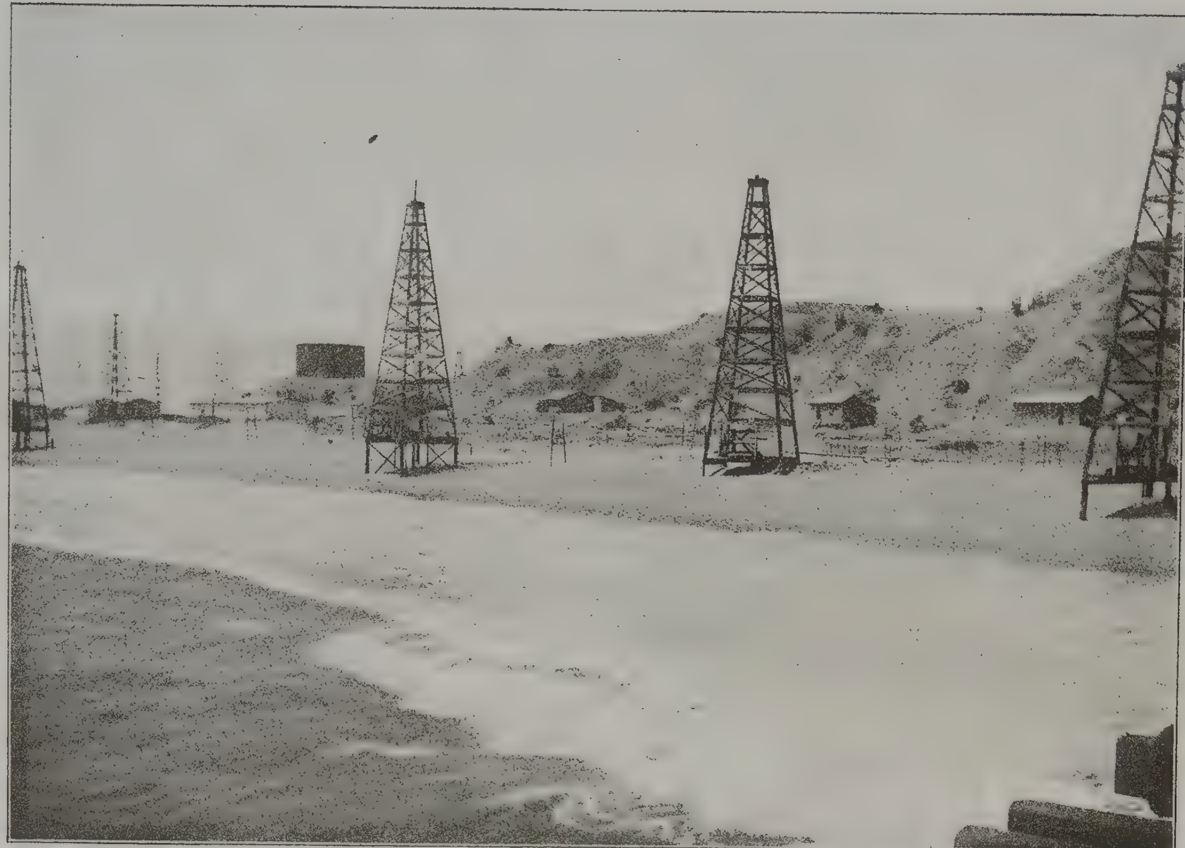
In 1883 Mr. Piaggio, now owner of the field, resumed drilling, and installed a refinery at Zorritos; and in duc course, built up a successful industry.

The property, which has an area of 731 acres, is situated on the coast, some 18 miles south-east from Tumbes. (Fig. 130.)

The oil wells of Zorritos line the coast for a distance of 3 miles, reaching north-eastward to within ⅓ mile of the Caleta Grau. The present[1] wells are almost wholly confined to a narrow strip of foreshore, having a width of 100-1000 feet. (Fig. 129.) Some of them have been drilled below high-tide mark. A few wells, however, have been placed in the mouths of the quebradas, extending back inland some hundreds of feet farther than the main zone of wells.

Bordering the long strip of foreshore, there is a line of cliffs, now abandoned by the sea, which have a height of about 100 feet. The land above them is a "tablazo" or plateau, 100 feet above sea-level. At about ¼ mile farther inland, this tablazo terminates at

[1] Latest observations were made in 1917.



Photograph kindly lent by Mr. Beeby Thompson, F.G.S.

Fig. 129.—Zorritos Oilfield.

Photograph kindly lent by Messrs. Beeby Thompson and Partners.

Fig. 130.—Zorritos Oilfield in 1920.

the foot of another cliff, which is topped by a tablazo at an elevation of 250 feet. The land is very rough, due to dissection of these tablazos by quebradas or canyons; and a few miles farther inland, there are precipitous hills rising to 1000 feet.

The Tertiary rocks, as seen in the cliffs behind the oilwells, are block-faulted and tilted, as in the other oilfields. The blocks here are fairly large, and the angle of dip is moderate, being generally from 5° to 15°. Near the coast, the majority of the blocks dip eastward or north-eastward. At a distance of several miles inland, some of them are nearly horizontal, whilst others are dipping towards the sea.

The Tertiary deposits seen in the Zorritos oilfield, consist of an irregular series of sandstones and conglomerate, some hundreds of feet thick, which passes down into a series of clay-shales having a thickness of several thousands of feet. (See Figs. 23, 24, in Part I.) Passage beds, between the sandstone series and the clay-shale series, consist of alternating beds of sandstone and shales.

Most of the wells are drilled on these passage beds. Many of them obtained the oil at a few hundred feet, but the best wells have a depth of 1000-1700 feet. Deeper tests, down to 2900 feet, failed to discover any further oil.

Evidently the oil occurs in the sandstones in the passage beds; and also apparently there is at least one important oil-sand at a depth of 1000 feet or more in the clay-shale series. But below this, the clay-shale series appears to be unproductive.

The author, however, has made only casual inspections of the geology at Zorritos; and therefore these

views are set forth as impressions rather than as proven facts.

The number of wells which have been drilled in the Zorritos field, during the past 40 years, is about 340. About a tenth of them are producers now.

Some of these producing wells are flowing, but the majority of them are pumping, the average yield per well being 7-9 barrels a day. Occasionally a 100-barrel well is obtained, and continues to flow for a year or more. Probably the best well was No. 313, completed in the year 1915, which at a depth of 1718 feet, came into production with a flow of 250 barrels a day.

The annual yield of the Zorritos field is 75,000-100,000 barrels; which is about 2·5 per cent of the present production of Peru.

The maximum output was 107,000 barrels, recorded for the year 1910. Up to the present date this field has produced approximately 2,000,000 barrels of oil.

The wells yield also a considerable quantity of gas, which is utilised for light, heat, and power, in the field.

Drilling rigs of the California type are used, and in some cases the machinery has been operated by gas engines.

The Zorritos oil is of high quality. It has specific gravity about ·830 (38·4 Beaumé), and contains 15-30 per cent of gasoline. The base is mixed. (See Chapter VI.)

The crude oil is refined at Zorritos, several grades of gasoline, kerosene, and lubricants being produced, as well as fuel oil.

The refinery has a daily capacity of 100 tons, and

there is tankage for 5000 tons of oil. The refined oil is cased in 5-gallon cans, which are made in a modern can factory.

The oilfield is equipped with a good machine shop, and a condensing plant for securing water supply from the sea.

The shallowness of the sea, at Zorritos, necessitated the construction of a steel mole, 1100 feet in length. The Company has its own tank steamer, which conveys the products of the refinery to Callao, for sale in Peru.

QUEBRADA TUCILLAL

In the upper part of Quebrada Tucillal, at a distance inland, behind the Zorritos oilfield, two wells were drilled by the Mancora Syndicate, in 1891–1892.

The first well found oil to the amount of about half a barrel a day, at 500 feet, but was finally abandoned at a depth of 826 feet.

The second well, which met with several good shows of oil, went down only to 390 feet.

Part of the machinery still remains on the ground, and some oil still flows out of one of these old wells.

EL GRILLO

Proceeding south-westward along the shore from Zorritos, the productive wells are found to terminate at a large fault-line, near the Quebrada del Poso. On the south-west side of the fault, the cliffs and hills consist of brown clay-shales. They do not contain any of the overlying sandstones which are seen at Zorritos.

Two wells were drilled on these brown shales by the Lobitos Oilfields Ltd., in 1912. They are situated some distance from the coast, in Quebrada del Grillo, the mouth of which is about ½ mile beyond the fault-line.

One of the wells, which was drilled to 3000 feet, struck gas and salt water; but only traces of oil were found.

HERVIDEROS,—QUEBRADA ZAPOTAL

Two miles inland from the coast, near Boca Pan, a well was drilled by the Lobitos Oilfields Ltd., in 1913.

The site of the well was in the Hervideros ravine, a branch of the Zapotal Valley, which joins the Quebrada Boca Pan near the sea.

Here there are hot mud-springs, with emanations of gas. The drilling was impeded by the quantity of salt water which was encountered.

The hole, which was sunk to a depth of 2500 feet, in 1913, was subsequently abandoned.

BOCA PAN

Proceeding farther south-westward along the coast, beyond the fault which terminates the Zorritos field, the Zorritos Sandstones soon reappear in the cliffs.

About 6 miles from Zorritos we arrive at Boca Pan, a small village which owes its existence to the presence of a water-hole, a few miles up the valley of Boca Pan.

On the shore, a mile south-west of the mouth of the quebrada, the Boca Pan Oilfields Company drilled

two wells, in 1913–1914. A heavy Californian rig was used, and though depths of 1800 feet and 2200 feet were reached, only gas and salt water were found.

CARDALITOS

About 10 miles south-westward along the coast from Boca Pan, and 24 miles north-east of Mancora, a drilling camp was established by the Cardalitos Oil Company, successors to the Boca Pan Company.

Here the newly upraised beach which has been abandoned by the sea, is nearly a mile in width. (The tree-cactus, *Cardo*, grows upon it in profusion.)

Two deep wells were drilled in the years 1914–1916, but except for salt water and some gas, only "colours of oil" were found.

The well on the claim "Pedro" had a depth of 2700 feet, and that on the claim "Edouardito" went down to 3900 feet.

It is stated that this venture cost more than £30,000.

LA BREITA

Fifteen miles inland from the coast at Mancora, and within a few miles of the mountains, there are seepages of heavy oil at a place known as La Breita.

In former times, "pez" or "brea" was worked at this place. Some of the old brea pits, about 10 feet deep, may still be seen; and there are also iron cauldrons in which the pitch was boiled.

The outcropping rocks in this vicinity have an odour of petroleum. They belong to the Tertiary

formations, and consist of dark sandy shale and beds of very hard calcareous sandstone; but their exact horizon was not ascertained.

A well was drilled beside the old brea pits, in 1905–1907, by Mr. Nicholas J. Taiman, of Paita, who deserves much credit for his persevering efforts at exploitation under great difficulties. (See Fig. 131.) The well went down to 455 feet, and is said to have struck oil at 90, 140, 196, and 442 feet.

Some of the oil was conveyed to the coast, in kegs, carried by burros, whilst several hundred barrels of heavy dark oil was stored in the old brea pits, where it remains to this day.

The derrick is still standing over the old well, from which there issues a small quantity of oil and gas.

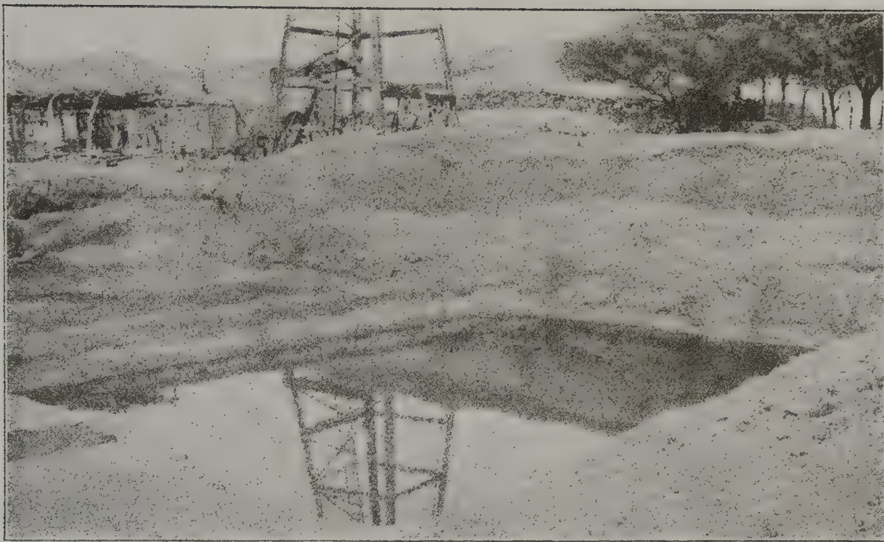
QUEBRADA SICHES

About 2½ miles inland from the coast at Cabo Blanco, in a deep dry valley, there are three shallow wells which were drilled by Mr. Taiman, probably in the year 1904.

Oil was found in each of these wells, but the difficulties of exploitation were great.

A road up the cliffs was constructed near Punta Verde, where the machinery was landed. Sea water was distilled at this place and was piped to the wells. The old boiler is still on the shore.

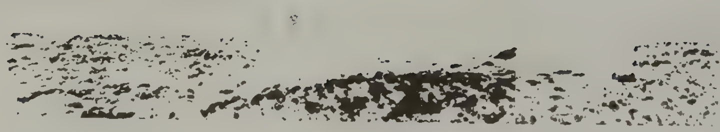
The rocks in Quebrada Siches probably belong to the Negritos Formation. They give rise to strong seepages of oil.



Photograph by T. O. Bosworth, 1914.

FIG. 131.—Taiman's Oilwell at La Breita, 15 miles inland from Mancora.

This well, located on the site of old brea workings, was drilled in 1905-7. A quantity of heavy oil was obtained, and was stored in the *brea* pits which are seen in the foreground.



Photograph kindly lent by Lobitos Oilfields Ltd.

FIG. 132. Oilfield at Punta Restin, Lobitos Oilfields Ltd.

Punta Restin is seen in the distance

LOBITOS; PUNTA RESTIN; CABO BLANCO

(Lobitos Oilfields Limited)

Along the coast from Cabo Blanco southward for some 15 miles, as far as Punta Capullana, the oil exploitations have been conducted by the Lobitos Oilfields Ltd., a well-known and prosperous British Oil Company.

Two oilfields, separate and geologically different, are included under the above heading,—the oilfield of Cabo Blanco (and Punta Restin) which is the newer field; and the older oilfield of Lobitos, situated 9 miles farther southward along the coast.

Oilfield at Cabo Blanco and Restin (Lobitos Oilfields Ltd.).

Oil claims to the extent of some 2700 acres around Cabo Blanco and Restin, were added to this Company's holdings in 1912. (Figs. 14, 15, 48, 132.) The value of the new field, which is separated from the Company's main oilfield by some 6 miles of apparently unproductive territory, was proved in the following year by the success of the trial wells at Punta Restin.

The oil wells in this area now extend along the coast from Punta Restin northward as far as Cabo Blanco, a distance of 5 miles. Most of the wells are along the shore, the farthest being on the north side of Cabo Blanco. (See Fig. 15.) But development inland also is now proceeding, though considerable difficulties had to be overcome, owing to the height of the cliffs, and to the deep dissection of the land.

There are now 75 wells in the Restin-Cabo Blanco

field, of which 45 are producing. Some of these wells have given as much as 200 barrels a day.

A number of sands have been found productive, at depths mainly 1000-2500 feet.

The rocks in this part of the oilfield belong to the Negritos Formation. They closely resemble the beds of that formation at Negritos, and contain similar pinkish-white bands of oil-sand. These rocks are parted from those of the Lobitos Formation to southward, by a fault, south of Restin; and likewise they are parted from the Lobitos Formation to the northward, by a fault, near Punta Neuron.

The strata are much block-faulted; and dip in various directions. On the coast, some of the more conspicuous blocks are dipping towards the N.N.W., at 20°.

The oil is somewhat heavier than that of the main Lobitos oilfield, which is produced from the Lobitos Formation. It has specific gravity about ·851 (34·5 Be.), and contains 18-20 per cent of gasoline.

The sea is deeper off Restin than at Lobitos, and tankers can come in near enough to be loaded from the shore by a marine pipe-line.

Between Punta Restin and Lobitos (Lobitos Oilfields Ltd.).

South of the Punta Restin oil wells, beyond the fault which has been mentioned above, the Lobitos Formation occupies the ground.

A number of trial wells were drilled by the predecessors of the Lobitos Oilfields Ltd., along this part of the coast, in 1901–1908, without success.

Oilfield at Lobitos (Lobitos Oilfields Ltd.).

The main oilfield operated by the Lobitos Oilfields Ltd., occupies several miles of coast-line around Punta Lobitos, and the Lobitos Bay. The exploited territory at this place has an area of about 1000 acres. (Figs. 22, 47; and Folders X., XI.)

The prospecting in this vicinity was begun in 1901, under the management of A. Milne & Company, of Callao, acting for a syndicate connected with the Peruvian Corporation.

The first success was met with by their Well No. 3, which struck oil at 400 feet. But oil in quantity was not found until 1905.

The Lobitos Oilfields Ltd. was formed to take over this property, and other holdings also, from the Peruvian Petroleum Syndicate, in 1908.

The production of the Lobitos Oilfield (together with that of the wells at Restin and Cabo Blanco), is now (March 1922) about 2300 barrels a day, which is 22·5 per cent of the present output of Peru. Up to the end of 1921, these fields have yielded more than 8½ million barrels of oil.

The number of wells drilled in the field at Lobitos, is over 300, of which some 120 are now producing. A few of these wells are flowing, and the others are being pumped. (Fig. 150.)

The average yield per well, in production, for the two fields together, is about 13 barrels a day.

The majority of the wells at Lobitos are under 2000 feet in depth—but these are producing much less than half the output of the field. They are mainly pumping wells, yielding from 5 to 100 barrels a day.

The greater part of the production is obtained from a smaller number of deep wells, 2500-4000 feet,—which have been drilled in recent years.

This deep drilling is found to be more profitable than the shallower exploitation; although the results are irregular, and consequently the cost is great.

The successful deep holes come in as flowing wells, producing sometimes as much as 500 barrels a day, of high-grade oil; and they continue to flow for several years.

One of the best wells on this property was Well No. 100, drilled in the year 1911, which, at a depth of 2600 feet, came in with an initial daily flow of 300 barrels. During its first two years this well produced at the average rate of 150 barrels a day. It is still yielding about 50 barrels a day.

Another good well was No. 169, which came into production at the rate of 500 barrels a day, at a depth of 2070 feet, and two months later was still yielding 400 barrels a day.

But the depth of some of the best wells, drilled more recently, is as much as 4000 feet.

Most of the drilling at Lobitos is done by British and Peruvian drillers, using cable tools; but Galician tools and Galician drillers also have been employed.

The oilfield is well equipped with excellent buildings, machine shops, sea-water distillation plant, offices, stores, club-houses, schools, etc. There is tankage for 30,000 tons of oil.

The oil of the Lobitos field is of high quality. The specific gravity is about ·838 (37 Be.) and the gasoline content 25 per cent.

There is no refinery at Lobitos; and at the

Photograph kindly lent by Lobitos Oilfields Ltd

Photograph kindly lent by Lobitos Oilfields Ltd.

This view shows a large tanker loading at the mole
which formerly used to rec

present time the output is disposed of to the International Petroleum Company, much of it being shipped to North America, along with the oil of the Negritos field.

The sea off Lobitos is shallow, and there is a heavy surf. A steel pier, 3384 feet in length, extends out into deeper water beyond the surf; but large steamers have to lie still farther off, and are loaded by means of a sea pipe-line from the pier.

The rocks exposed in the Lobitos field belong to the Lobitos Formation. They consist of grey clay-shales, alternating with thin beds of yellowish calcareous sandstone. (Figs. 21, 22.) The deposits are block-faulted; and the blocks dip in various directions, at angles of 10°-20°.

As a consequence of the faulting, the results obtained on drilling vary greatly from well to well—(as they do in all the Peruvian fields). Thus it is not practicable from the results of drilling only, to determine the number of oil-sands in the field, or to correlate the sands encountered in different wells. In many of the wells the productive sands were reached at 1100-1400 feet, but the best wells in the field produce from sands lying at a depth of 2000-2500 feet, and during the past few years a rich oil-sand has been exploited by wells 3800-4000 feet deep.

Possibly within the small area on which the producing wells of Lobitos are drilled, the displacements by faulting may be comparatively small. At any rate the above facts have led to the view, in this oil-field, which may or may not be correct, that the production comes from three principal oil-sands, at depths of approximately 1300, 2400, and 3900 feet.

NEGRITOS; LAGUNITAS; AND LA BREA

(International Petroleum Company)

The Hacienda La Brea y Parinas, an estate of 656 square miles, occupies the coast-line south of Lobitos, for about 36 miles, extending from near Punta Capullana almost to the Rio Chira.

This territory, now owned by the International Petroleum Company, has been the scene of many and various exploitations. It includes the largest oilfield of South America.

The village of Negritos, which is the headquarters of the drilling field, is situated on the coast, 2 miles north-east from Punta Parinas, almost in the middle of the coast-line of the estate. (Figs. 133, 134.)

The smaller village of Lagunitas, which was formerly the drilling camp of a separate company, lies 4 miles inland south-east from Negritos. (Fig. 127.)

La Brea, the principal site of the ancient brea workings, and now surrounded by modern oilwells, is still farther inland, being 12 miles due east of Negritos.

Talara, the port of the oilfield, and the site of the refinery and main offices of the Company, is on the coast 6 miles north of Negritos and 10 miles south of the Lobitos field. (Fig. 126.)

The exploitation of the Negritos oilfield was commenced in prehistoric times, when pitch or "pez" was obtained from open pits. The work was continued by the Spanish conquerors in Colonial days, being then a monopoly of the Crown.

Several groups of old diggings around Negritos,

known as the King's Brea Pits, besides the extensive workings at La Brea, still mark the site of this industry of former days.

Drilling at Negritos is said to have been commenced in 1873–1874, by Mr. Henry Meiggs of Lima. It was continued by the firm of J. B. Mulloy & Company. (See Chapter III.)

The earliest wells of which record is preserved, were drilled by Mr. E. Fowkes, who was in charge of the operations in 1875.

The first well, which was 330 feet deep, is reputed to have produced at the rate of 400 barrels a day, and to have continued to flow for 7 months. The second and third wells were of about the same depth, and gave similar results.

But during the war with Chile, the buildings and plant were destroyed, and operations were abandoned.

The property, with all its rights, was purchased from Don Genaro Helguero, in 1888, by Dr. H. W. C. Tweddle, for the sum of £18,000. This gentleman, together with Mr. Henry Keswick, founded the London and Pacific Petroleum Company, in 1889.

The field was very successfully developed by this Company during the ensuing 24 years; though so large was the expenditure in constructing this great industry in the desert, that profits were not taken out of the business by the share owners, during all that time. The amount of the investment was estimated at £1,200,000.

In the latter part of 1913, the property was sold to the International Petroleum Company of Toronto. Up to the end of that year, the number of wells drilled was about 700; and the output had reached a figure of 3500 barrels a day.

The Lagunitas Oil Company, of London, meanwhile had exploited part of an area of 4 square miles, around Lagunitas, inland 4 miles south-east of Negritos, which they had leased from the London and Pacific Petroleum Company in 1910.

This Company had drilled about 170 wells and had developed a production of 1400 barrels a day, when they also were taken over by the International Petroleum Company, in 1916.

The whole field at Negritos and Lagunitas has now been much extended by the operations of the International Petroleum Company (who also have opened the new field of La Brea). Altogether some 1500 wells have been drilled, and there is an output of nearly 8000 barrels a day.

The oil industry in the fields of Negritos, Lagunitas, and La Brea, has been long established, and now represents a very large investment. It supports in comfort, in the desert, a population of 6000-10,000 Peruvians, besides a large community of Americans, Canadians, and British.

The International Petroleum Company takes much care for the welfare of all its people, and has provided for them many of the comforts, as well as the necessaries, of life.

The villages of Talara, Negritos, and Lagunitas, which were built by the oil companies, contain churches, schools, hospitals, markets, sports grounds, and clubs. The whole population has been supplied with pure water, distilled from sea water. The cost of running the distillation plant was estimated to exceed £41,000 a year. A water pipe-line, 24

Photograph by A. H Low, 1920.

Fig. 133.—Negritos.

The buildings shown in this view face the sea. The house in the foreground is the geologists' quarters. Beyond it, on the right, are the Club-house and tennis-courts At the right edge of the picture a part of the football ground is seen. The white house, a little to the left of the centre, is the hospital.

Photograph by A. H. Low.

Fig. 134.—Negritos Bay.

The dark buildings are the towers of the water-condensing plant. The mole, and beyond it some cliffs of Parinas Sandstone, are seen in the distance.

miles in length, from the Rio Chira, has now been built.

The drilling in this field is done with standard cable tools. Besides British and North American drillers, a number of good Peruvian drillers have been trained in these fields. Many Peruvians are employed also as skilled mechanics, carpenters, etc.; and also in the clerical work.

Talara, 6 miles north of Negritos, is the Company's shipping port and also the site of the offices, tank farm, refinery, canning plant, etc. (Fig. 126. See also Fig. 20 in Part I.)

The tank farm has storage for 1,000,000 barrels of oil. (See Folder No. XI., and Fig. 20.)

The refinery has been rebuilt and much increased in recent years. (Figs. 145, 146.) It has a capacity of 7000 barrels a day, and is well able to supply all the requirements of Peru for all refined oil products.

The surplus of crude oil is shipped to refineries in Canada and the United States, a large fleet of tankers being engaged in this transportation.

Talara bay has been developed into one of the best harbours on the Pacific coast. (Folder No. XI. (2).) An excellent steel and concrete pier and wharf has been constructed, at which large vessels can be loaded easily and quickly. So considerable is the Company's shipping business, that Talara now ranks as one of the chief ports of Peru.

The Oilfield around Negritos and Lagunitas.

This main oilfield of the International Petroleum Company now covers a continuous area of 16 square miles, extending 6 miles inland, and occupying the

coast north and south of Punta Parinas for a length of 8 miles.

[In deference to the above-named Company, no detailed account of this oilfield is here presented by the author. With the exception of a few general comments, sanctioned by the Company, the development and conclusions, of the past 8 years, are excluded from this description.

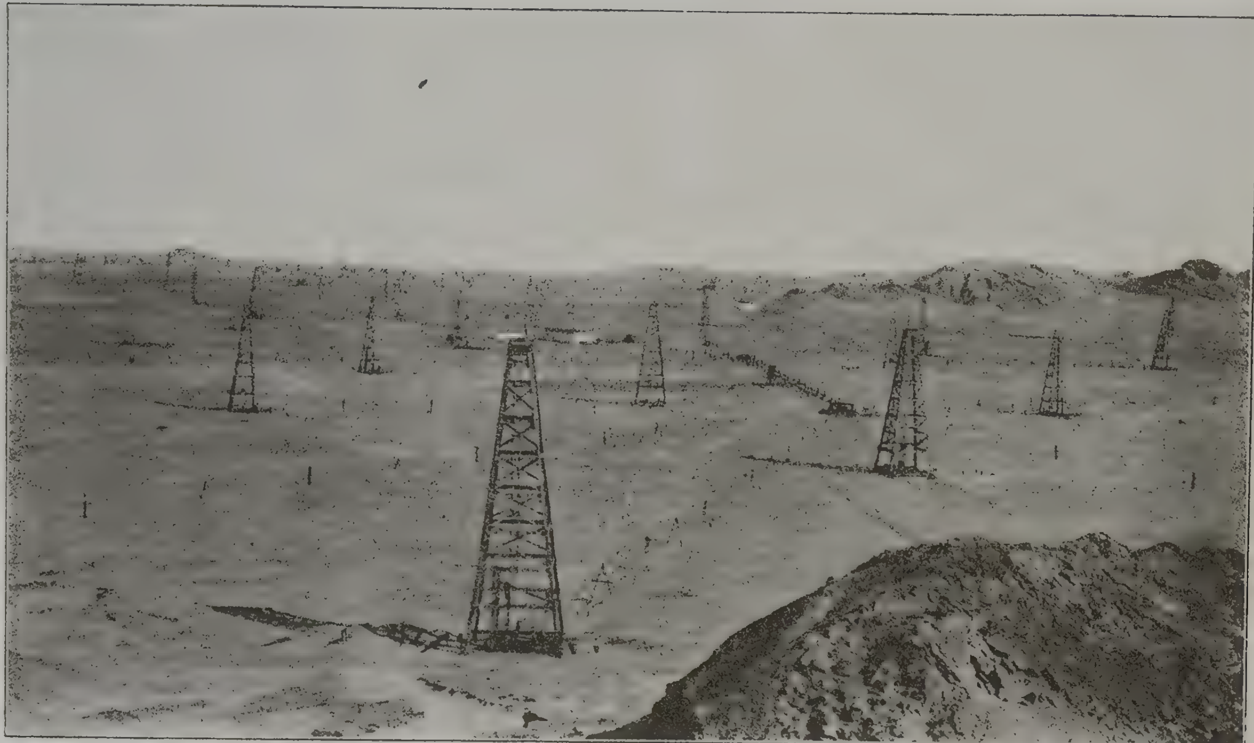
The following brief remarks, however, convey some idea of the oilfield, and relate a few of the most obvious facts established in the earlier years of the exploitation, — before the present Company made acquaintance with this field.]

The elaborate character of the block-faulting in this oilfield, gives the geological map a " patchwork " appearance. (See Folder No. II. in Part I.) In many places the adjoining " patches " have, at their surfaces, beds which belong to horizons several thousands of feet apart. The blocks are, in fact, parted by faults having thousands of feet of throw.

The oilwells (drilled by the English Companies) occupied 8½ square miles, and extended over many fault-blocks. They stood on various different formations, which had altogether a stratigraphic range of probably 8000-9000 feet.

The earliest wells were situated at Negritos, on beds of the Negritos Formation.

These beds here occupy an area of some 10 square miles at, and around, the village of Negritos. (Fig. 5.) The strike of the fault-blocks in this area is generally in a north and south direction, and the strata dip eastward at 20°-30°. But both strike and dip vary



Photograph by T. O. Bosworth, 1913.

Fig. 135.—Negritos Oilfield. An old part of the field, 1 mile S.S.E. of Negritos.

Fig. 136.—Negritos Oilfield. An old part of the field. Oilwells and salt on the Salina Grande, 2 miles south of Negritos.
View looking south-eastward. The Yegua Blanca hill, formed by the Parinas Sandstones, is seen in the distance.

widely from block to block. The outcropping strata have a stratigraphic range of 4500 feet.

The " King's Brea Pits " (and also the first drilled wells), are situated in this ground.

The largest of the old brea workings is on the Salina immediately south of the houses of Negritos, at a place where a few hummocks of oil-sand cropped up through the desert sand. The rocks belong probably to the Turritella Series of the Negritos Formation. Another group of diggings occurs 1½ miles farther south, on the Salina, 1¼ miles south-east of Parinas Point.

Much of the production in this portion of the field has come from an oil-sand, 50-80 feet thick, which occupies a position 1500 feet below the top of the Turritella Series. This sand was called the " Main Sand," though in later years other sands were found elsewhere, which have given more production. As the development advanced eastward (see Fig. 9), the depth to the Main Sand increased. At length about 2 miles from the coast, the wells which reached the sand were 3500 feet deep. (See Fig. 144.)

Some of the deep wells to the Main Sand have yielded 300-500 barrels a day, and flowed for many months.

Above the Main Sand, there are numerous other oil-sands throughout the Turritella Series and the Clavilithes Series, which have yielded valuable production, though most of the wells were of rather small capacity. (Figs. 123, 135.) Some of these pumping wells have continued to yield steadily for many years. Well No. 8, for example, which was drilled in 1899, to a depth of 545 feet, is still (according

to a recently published article[1]), producing a few barrels a day.

This area of rocks of the Negritos Formation, was, for a number of years, providing the greater part of the oil output of Peru.

Soon the oilfield expanded beyond the ground occupied by the Negritos Formation; and wells were drilled in the surrounding areas of Lobitos Formation.

At the northern end of the oilfield, some wells situated on this latter formation, obtained good production by drilling down through these strata into the Parinas Sandstone, which is the topmost member of the Negritos Formation.

This sandstone series, which is about 1000 feet thick, consists of thick beds of sandstone and conglomerates, with some thick and thin beds of clay-shale between them. The beds here strike in a general northerly direction, and dip inland at 20°-30°. Their outcrops form several miles of sea cliffs, along the coast in this vicinity.

The oil was struck generally near the base of the Parinas Sandstones, in a bed which may be called the Arbol Sand. Some fairly good flowing wells were obtained. But in some wells there was trouble due to the presence of much water in the sandstones above the oil horizon.

The chief production from the Parinas Sandstones was obtained at the southern end of the oilfield, 4 miles S.S.E. of Negritos, where a rich area was discovered on the Salina Grande. This part of the field,

[1] "The Lamp," December 1921.

Photograph by T. O. Bosworth, 1913.

FIG. 137.—Drilling Well No. 677, one of the early wells in the rich territory known as "Section 38," on the Salina, 4 miles south-east of Negritos.

Photograph by G. Sammons.

FIG. 138.—The Lagunitas plot, in the Negritos Oilfield, 1920.

This view shows the little village of Lagunitas which was built by the Lagunitas Oil Company.

known as Section 38, adjoins the south-west corner of the Lagunitas plot. (Figs. 124, 137.)

No outcrops occur at this place, but it is almost certain that the rocks, under the desert sand, belong to the Lobitos Formation. From the thickness of the sandstone series in which the oil occurs, it was concluded that the wells went down through the Lobitos Formation, and produced from the Parinas Sandstones beneath.

It was thought that the oil came chiefly from one bed in the Parinas Sandstones, which for convenience, may be called the Salina Sand.

The early wells, which were 1000-1500 feet deep, flowed for many months at the rate of several hundred barrels a day. The discovery well came in with an initial daily flow of 500 barrels; and soon there were a number of good wells.

In some instances, however, a large amount of water was encountered here within the Parinas Sandstones.

A considerable amount of gas also was obtained from these wells, some of them yielding several million cubic feet per day. Besides being used for the pumping engines, the gas was piped to Negritos and Talara, for use as fuel in the refinery, and the water-distillation plants, etc.

The oil from this part of the field was of high quality, having specific gravity about ·805 (44° Be.). It was said to contain 30 per cent of gasoline.

To eastward, the exploitation of the Negritos field soon extended to the border of the field developed on the Lagunitas plot. This area of 4 square miles, lying 4 miles south-east from Negritos, was exploited

by the Lagunitas Oil Company, in the years 1909–1916. (See Figs. 127 and 138.)

Up to 1916, rather less than 2 square miles of ground had been developed; 170 wells had been drilled; and the output had grown to 1400 barrels a day.

The rocks exposed are clay-shales, and gritty sandstones, of the Lobitos Formation (southern facies); and the fossils suggest that they belong to a horizon higher up than those fossiliferous beds which occur in the lowest 1000 feet of the formation.

The productive sands were found at depths ranging from 150 to 2500 feet. So numerous were they, that it was almost impossible to specify any of them individually; and in many wells the perforations were placed at short intervals most of the way down.

In the greater part of the plot, except perhaps in the case of the deeper wells, these oil-sands were within the Lobitos Formation; but in the west and south-west part of the concession, the wells probably produced from the Parinas Sandstones.

There was considerable variation in the oil obtained in this territory. Many of the early wells, in the west and south-west part, gave an oil of specific gravity as low as ·79-·78 (47 Be.-48 Be.), which is probably the lightest oil produced in Peru.

Some of the wells came into production at the rate of 200-400 barrels a day. Occasionally, holes only 200 or 300 feet deep, commenced as flowing wells.

The Exploitation of Former Days at La Brea.

La Brea has been the scene of the oldest, as well as of the newest, petroleum exploitations in Peru.

Photograph by T. O. Bosworth, 1913.

Fig. 139.—The ancient "brea pits" at La Brea.

This view shows one of the long trenches, containing oil.

Photograph by A. H. Low, 1920.

Fig. 140.—The ancient Brea Refinery at La Brea, surrounded now by modern exploitation.

In prehistoric time the heavy oil from the brea pits was boiled down in earthen pots. The stockade surrounding the "ovens" was built of the discarded pots, which in course of time became filled up with solid dross. In the foreground are four of the large iron cauldrons which were employed in more recent times. In the background, the Amotape Mountains are in view.

The "King's Brea Pits" at this place, were probably the most important in the country. They are quite extensive diggings which have been worked continuously for many centuries, dating from prehistoric times up to within about 10 years of the present day.

The ancient workings are situated on the great alluvial Breccia Fan, $2\frac{1}{4}$ miles from the foot of the Amotape Mountains, and $12\frac{1}{2}$ miles inland, due east of Negritos. (Figs. 125, 139.)

The diggings, which occupy an area 2000 feet in length and 500-1000 feet wide, consist mainly of long trenches, 15-20 feet deep, arranged in an orderly manner, and with the bottoms divided into compartments. Most of them still contain heavy residual oil. (See Fig. 139.)

In some of the pits, the oil-sands of the Negritos Formation are encountered a few feet below the surface, but generally they have only been reached at the bottom of the pits, or have not been touched at all. The oil, however, finds its way up from the buried outcrops of the oil-sands, into the pits, and also appears as natural seepages at the surface.

The crude oil, or "pez," was esteemed according to its density. For most purposes the raw material was too limpid, until it had been thickened by evaporation.

Beside the pits, are the ruins of the old works, or brea refinery, in which the "pez liquido" was boiled down, until it became the sticky or solid brea, which was the commercial product. (Fig. 149.)

This evaporating plant was of a primitive, though effective, kind. It consisted of rows of large earthen-

ware boiling-pots, with stonework fire-places or ovens built underneath them. Evidently, after a number of evaporations had been performed, the pots became choked up with pitch and dross, and had to be discarded. The stockade, surrounding the works, is largely built up of thousands of these discarded pitch pots, filled with their black pitchy residuum.

In later times, iron cauldrons were introduced in place of the earthen pots. A number of these may still be seen amid the ruins. (Fig. 140.) When first visited by the writer, in 1912, one or two of the cauldrons were in position, just as they had been when the last evaporation was performed.

This process was in operation at La Brea until about 1910. It was last worked by Peter Sayres. The solid product was conveyed on burros to Talara, from which port it was shipped up and down the coast to Tumbes, Payta, and other places, where the inhabitants used it for lining their earthen liquor jars, and for other purposes. (See Chapter III.)

The Oilfield at La Brea.

Three old wells, near the brea pits, record the first attempt at exploitation by more modern means. These holes, which are believed to be 1000 feet deep, are said to have been put down by Mr. Fowkes about 45 years ago: but no commercial production was developed at that time. Water, gas, and a little oil is still issuing from these old wells. A drilling stem and jars, found in the mouth of one of the wells, bears the inscription "Titusville 1876." The casing of this well is seen projecting from the bottom of a dug well, 30 feet deep, which has descending steps.

Photograph by A. H. Low.

Fig. 141.—The La Brea Oilfield.

View showing several of the wells, an oil-tank, and, on the left side of the picture, the two towers of a water-condensing plant. All are situated on the surface of the great Breccia Fan. The Amotape Mountains are well seen in the background.

Photograph by A. H. Low.

FIG. 142.—La Brea. Inside the derrick of a Well. Gas, water, and mud being ejected on withdrawal of tools.

The box in foreground is used for collecting well cuttings

The important exploitation of the La Brea field was commenced by the International Petroleum Company in 1916. Some 60 wells have now been drilled. Evidently the oil is obtained from sands in the Negritos Formation, beneath the Breccia Fan.

The oil wells extend alongside the "Camino Real," the public trail across the desert, leading from Payta to Tumbes. They are seen to occupy an area around the old brea pits, reaching northward of them for half a mile, and to southward for 1 mile.

One of the producing wells is within $1\frac{3}{4}$ miles of the mountain flanks, and the distance between the main group of wells and the mountains is only 2 miles. It is not surprising, therefore, that the Amotape slates and quartzites were reached in several of the holes.

The La Brea oil has an asphaltic base, and is considerably heavier than that of the other oilfields. The oil from the early wells was reported to have specific gravity about ·90. The gasoline content was about 5 per cent, but the oil was serviceable for making lubricants.

The initial development at La Brea was an expensive undertaking, on account of the lack of water and the distance from the coast. A railroad across the desert had first to be built, in order to adequately transport the machinery and supplies. Then water, distilled from the sea, had to be conveyed by tank cars to the field, for drilling. The output, in the early stages, likewise had to be taken to the coast by rail.

Talara District—Unproductive Test Wells.

Around the Negritos oilfield, at a distance from it, in several localities, test wells have been drilled which have not led to any present production.

Thus at Punta Malaca, 3 miles north of Talara, one or two holes were drilled, in 1920–1921. The rocks here belong to the Lobitos Formation (northern facies), and are dipping northward at 10°-15°. About a mile south of Talara, on the low sandy plain, or salina, 2 wells were drilled many years ago, near the foot of the Tablazo cliffs. It is said that their depth was about 1000 feet, and that only gas was found.

On the Tablazo, 1½ miles S.S.E. of Talara, also a well was drilled about 6 years ago.

Midway between Talara and La Brea, about 6½ miles inland, a test hole was in progress about 2 years ago.

LECHUSAL

About 3 miles north of the Rio Chira, and 3 miles inland, a hole was drilled to a depth of 130 feet, by a local Peruvian syndicate, in 1913.

This well, which was 23 miles south-eastward from Negritos, was located on rocks of the Lobitos Formation.

It was reported that a show of oil was obtained; but evidence of this was not perceived. Eventually the hole was abandoned.

BAYOVAR

The occurrence of petroleum at Bayovar, must be mentioned in this chapter; for although that district is not included within the limits of the area specially described in this volume, it nevertheless belongs to the same geological region, and contains the same rocks.

Bayovar is a group of fishermen's huts, on the shore of a good harbour, 46 miles south of Payta. This place lies on the north side of a mountain mass, some 40 miles in length, named Cerro Yllesca, which forms a large promontory on the coast.

The mountains, which consist of granite intruded into ancient slates, are an outlier similar to the Cerros de Payta, though considerably larger. Presumably this mass was an island in the Tertiary, as well as in the Quaternary, sea.

The mountains are surrounded by the Tertiary rocks; though these are much concealed under Quaternary deposits and desert sand.

At a place called Reventazon, on the south-east side of the mountain mass, sulphur has been mined in the Tertiary rocks. These workings were connected, by 26 miles of narrow-gauge railroad track, with the harbour of Bayovar, where a steel mole, 330 feet in length, was built to facilitate shipment of the sulphur.

Oil seepages (see Chapter II.) have long been known in this district, especially on the south side of the mountains, at La Garita, where fairly large outcroppings are seen. At Bayovar, and also at Reventazon, oil seepages are reported.

At La Garita, a well, 300-400 feet deep, was drilled for Don Frederico Blume, of Lima, about the year 1900. A small quantity of oil was found.

On the north side of the mountains, near Bayovar, the Bayovar Development Company, which was formed in 1911 by Mr. T. P. Murphy, drilled two or three shallow holes. After penetrating through a small thickness of shales, the drill entered the hard mountain rocks, and the work was eventually abandoned.

Bayovar was not visited by the writer, but fossils collected here, which were shown to him, belonged to the Clavilithes Series of the Negritos Formation.

LOBOS ISLANDS

On the Lobos Islands, which lie some 40 miles south-east of the Cerro Yllesca mass, there are conspicuous seepages.

Here there are extensive old workings (brea pits) which were known to the early Spanish explorers, and from which, in past days, heavy oil or pitch was obtained. (See Chapter III.)

CHAPTER V

RELATIONS BETWEEN THE GEOLOGY AND THE OCCURRENCE OF THE PETROLEUM

Stratigraphic Range of the Oil.

The Petroleum in the Littoral region of northern Peru, so far as is yet known, is confined to the Tertiary Formations. None has been found in the Mesozoic or older rocks, and such seepages as are noticed on the surface of the Quaternary sediments and other superficial deposits, are plainly emanating from covered outcrops of the Tertiary beds a few feet beneath.

Within the Tertiary, the occurrence of the petroleum ranges through a remarkably large column of strata. The production is obtained from many different horizons throughout the Eocene and Miocene.

The upper 2000 feet of the Zorritos Formation contains the many oil-sands which have yielded all the oil of the Zorritos oilfield, and also that of Quebrada Heath.

Some 4000 feet of the Lobitos Formation (northern facies) include the various oil-sands from which the oil at Lobitos has been obtained.

Probably 4000-5000 feet of the Lobitos Formation (southern facies) contains the very numerous oil-sands which have produced the oil in the Poso valley and Lagunitas plot of the Negritos oilfield.

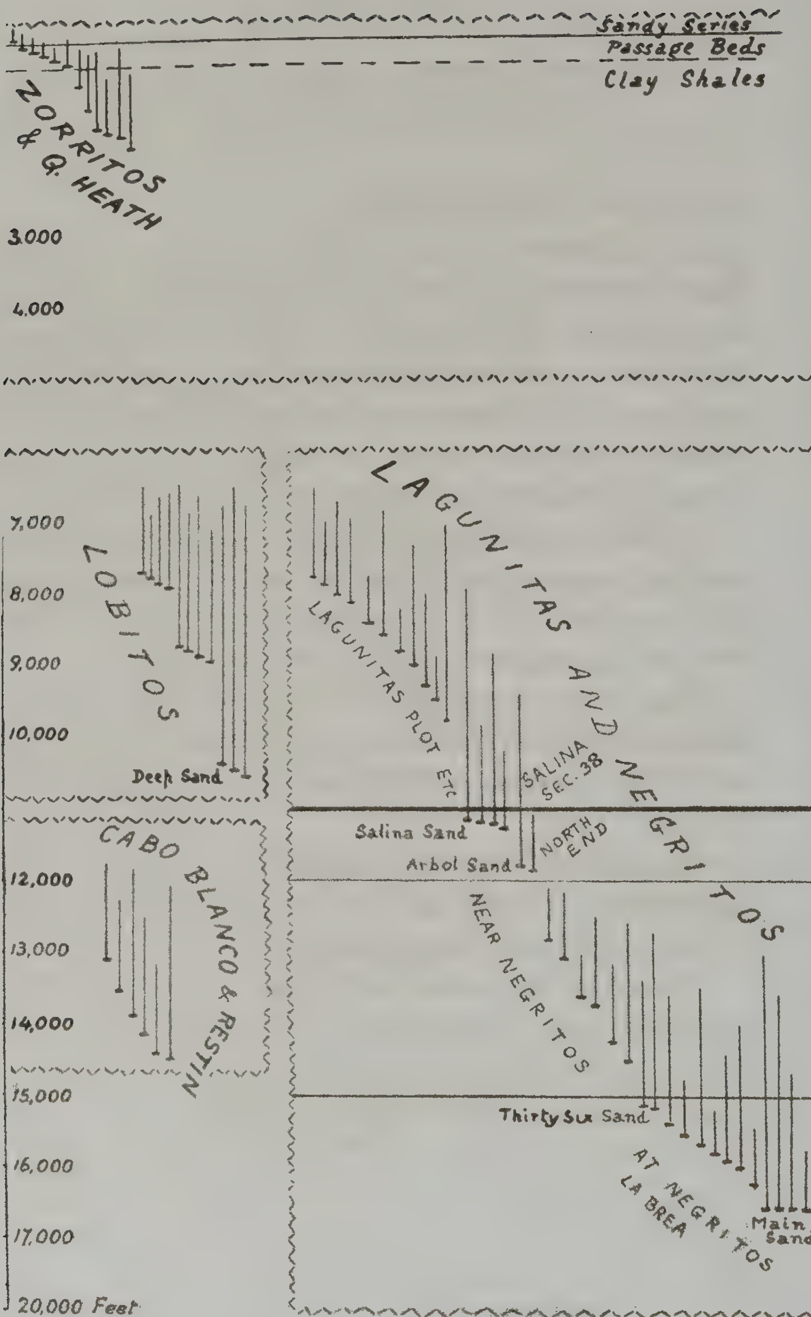


FIG. 143.—Diagram to show Stratigraphic Range of the Producing Oil Hori

The 1000 feet of the Parinas Sandstones include the oil horizons of the north end of the Negritos field, and the prolific oil-sands of "Section 38" at the south end of the field.

The 3000 feet of shales of the Clavilithes Series of the Negritos Formation, below the Parinas Sandstone, contains many productive sands throughout, in the older part of the Negritos field. They are the productive formation also in the Cabo Blanco (Restin) oilfield.

The upper 1500 feet of the Turritella Series, contains the "Main Oil-sand," and the many other productive sands, which yielded the greater part of the oil in the oldest portions of the Negritos field. The oil-sands of the La Brea field are in this series, as also probably are some of the lower oil-sands of the Cabo Blanco field.

The lowest 1500 feet of the Turritella Series which have been penetrated, and which are known only to the drill, have not yielded production.

Thus, tabulating the facts below, we see that the productive oil-sands in this region are very numerous, and range through at least some 15,500 feet of the Tertiary Formations.

Zorritos Formation, 5000 feet +	Upper 2000 feet productive in the Zorritos field, etc.
Lobitos Formation, 5000 feet +	At least 4000 feet productive at Lobitos, and in the Lagunitas and Pozo portions of the Negritos field.
Negritos Formation, 7000 feet +	Upper 5500 feet productive in older part of the Negritos field. Also part is productive at La Brea, and in the Cabo Blanco-Restin field.

The Oil-Sands.

In most of these oilfields the results of drilling vary, to an unusual degree, from well to well. Often the sands which are productive in one well are not the same sands which yield the oil in the next well.

This may be due partly to lenticularity and lateral variation in the strata, but most likely it is a result of the excessive faulting, which has given to every acre of ground differences of attitude and history, and which has allowed many irregular paths for movement of oil from one sand to another.

But, whatever be the cause, it is clear that in much of the oil territory there are a large number of different oil-sands.

In some localities certain particular oil-sands have been identified over considerable areas. Such, for instance, are the Main Sand, and the Thirty-Six Sand, in the older parts of the Negritos field; the Arbol Sand at the north end of the field; and the Salina Sand at the southern end of it; also the Deep Sand at Lobitos.

The preceding diagram illustrates the range of the horizons which at present are productive in these oilfields. **(Fig. 143.)**

Relation of the Oil to the Ancient Shore-Line.

The shore-line of the Tertiary Pacific Sea, lay along the foot of the Amotape Mountains (as has been shown in Part I. of this book). Approaching the mountains, the Tertiary deposits become coarser in character; and where they rest against the steep mountain slopes, they consist mainly of sand and shingle.

The mountains project up through the Tertiary Formation abruptly and sharply. Clearly this must have been a steep and rocky coast.

The old coast-line can be traced, all along the mountain flank, and can be marked upon a map. On the map, Fig. 1 in Part I., the west margin of the mountain rocks may be taken as this Tertiary shore-line.

The position of the coast-line was not, of course, constant throughout the whole Tertiary period. As the earth's crust slowly subsided, and the pile of Tertiary deposits accumulated, the mountains were becoming gradually more deeply submerged in these sediments; and consequently the coast-line must have been shifting eastward. Owing to the steepness of the mountain slopes, however, this eastward shifting may have been comparatively small.

Speaking generally for the Period, the conditions probably were as follows:—A Tertiary Pacific Ocean extended up to the foot of the outer range of the Andes. To northward, in the region of Guayaquil, a large river entered this ocean. To southward, in the region of the Chira and Piura valleys, a smaller river entered. The sea-shore, in the present oilfield region, was along the flank of the Amotape Mountains; and farther southward, it continued along the flanks of the Piura Mountains. The mountains of Payta were a rocky island, as also was the mountain mass of Cerro Yllesca.

The oil in the La Brea, the La Breita, and the

Bayovar districts, in each instance is very near to the shore-line of the deposit. That at La Brea is certainly within 2 miles of its shore-line, for 2 miles east of the brea pits there are sharp hills of the mountain rocks, with coastal deposits lying against them. At La Breita also, the distance apparently is less than 2 miles.

It is to be noted that the oil in these places is of a much heavier and more asphaltic character than that of the fields which are farther away. The oil at La Brea, 2 miles from the shore-line, has specific gravity ·88-·91. In a well 2½ miles from the mountains the oil has specific gravity ·87.

The oil in the wells of Negritos and Lagunitas, which are 9-15 miles distant from the mountains, varies considerably, but all the important production has density between ·785 and ·865. The variation does not follow any perceptible rule, though it is noticeable that there is heavier oil in the lower part of the Negritos Formation which apparently was of shallower-water origin, as indicated by the numerous seams of beach pebbles and by the plant particles in the shales.

The high-grade oil of Lagunitas and of the south end of the Negritos field, which has density about ·79, is 13 miles distant from the mountains.

The oil at Lobitos, which is about 16 miles from the probable shore-line of the deposit, has specific gravity ·84.

The oil in the Cabo Blanco-Restin field is 20 miles from the mountains, but the rocks here are of Negritos age and were deposited in shallower water than the oil formation at Lobitos. The specific gravity of the oil is ·85.

The oil at Zorritos, which is 14 miles from the mountains, has specific gravity about ·83.

Relation of the Oil Accumulations to Structure.

The geological structure in the Peruvian oilfields (as explained in Part I.) is elaborate. The rocks are not folded but are intensely "block-faulted." The pile of Tertiary deposits is carved up into innumerable separate blocks, by a network of large faults, which often represent vertical movements of several thousand feet.

Along these large fault-lines, often irregular belts of crushed and broken rock occur, though very many of the faults are clearly cut and are well defined.

The blocks determined by the large faults are of all sizes, from an acre or less, up to several square miles. These large blocks are still further dissected by countless smaller faults.

Frequently a group of adjacent fault-blocks may be nearly in line, and may have "dips" which do not differ by more than a few degrees. But in general the fault-blocks are independent, and each one has its own individual strike and dip.

The attitude of the fault-blocks follows no rule. Along the coast there are blocks dipping in every direction, though in the Negritos field most of the blocks are dipping towards the east. Near the mountains the dip is generally directed seawards. The angle of dip very rarely exceeds 35°, and generally it is less than 20°. In the Negritos district, however, the dip of the blocks is usually between 20° and 30°.

With such structures, it is not surprising that the

results of the drilling in the Peruvian oilfields are very inconsistent. These oilfields abound in instances of wells, side by side, which have met with quite different results, and of wells which struck a large flow of oil, whilst the surrounding wells found little or none. In certain localities where most of the wells have penetrated thick sandstones, there are occasional wells situated amongst them which have been drilled deep without finding anything but shale.

In some places where the fault-blocks are large enough, the sequence of rocks below ground can be determined from the superficial geology. But though on the surface the boundaries of a fault-block may be clearly defined, yet many of the fault-planes are inclined, and extend underneath the unbroken rocks. And in general, where the faults are many and the blocks are small, it is unsafe for a geologist, or for any one else, to make predictions as to what will be found on drilling.

The causes for the inconsistencies are many. Owing to the complicated movements of the fault-blocks, and to the irregularities along their contacts, oil has been able to move about from one sand to another, and from one block to another, until it has become distributed according to no regular design. Probably in many cases, the oil-sands within a fault-block are sealed by contact with the clay-shales of the contiguous blocks and by crushed debris along the fault-planes. Thus the fault-block behaves as an independent unit, whose sands are more or less saturated with oil. In other cases, the sands of one block are brought into touch with different sands in another block, and the body of oil is contained jointly by the

two different sands. Again, usually along a crush-belt the sheared and crushed shales are impervious and unproductive: yet in some cases, large masses of sandstone are entangled in the crush-belts underground, and may act as storage for the accumulation of oil.

In general, the block-faulting in the Peruvian oilfields has had somewhat the effect of dividing the petroliferous territory into cells. This accounts for the rather wide extent of the productive areas, and the moderate size of the wells. There is here a lack of that concentration of the oil which occurs in anticlinal oilfields, and which results in larger wells and smaller area of production.

The geological study of these oilfields has failed to establish any definite principle governing the distribution of oil in the fault-blocks.

The oil does not seem to be more abundant at the upper edge of a block, or near the faults, or in the middle. But rather, irregularity of distribution appears to be the rule.

In many cases wells located on fault-lines or on crush-belts were a failure. But in yet other cases, such wells proved to be a conspicuous success. There is no evidence, however, that oil comes up fault-cracks or fissures.

The most consistent results in all the region, were obtained in the Negritos field, in that portion of the field where the largest and most unbroken fault-blocks occur.

This ground lies north and east of Negritos. It

consists of three large fault-blocks, each from $1\frac{1}{2}$ to 3 square miles in area, which are very little further broken up by faulting. These are some of the largest unbroken fault-blocks observed, in the whole region. They extend from near the coast of Negritos, as far as the Poso Valley, 3 miles inland. (See map, Folder No. II.)

A sequence of 6500 feet of conformable strata, is clearly exposed, at outcrop, in these blocks, dipping inland at an angle of 22°-24°. The beds exposed consist of :

1000 feet shales of the Lobitos Formation.
1000 feet Parinas Sandstone of the Clavilithes Series, Negritos Formation.
3000 feet shales, etc., of the Clavilithes Series of the Negritos Formation.
1500 feet shales, etc., of the Turritella Series of the Negritos Formation.

The development of these blocks commenced at their western ends, where many flowing wells were obtained at depth of 700-1500 feet, from an oil-sand about 70 feet thick, subsequently known as the "Main Sand."

As the oilfield was advanced eastward, this sand was found to be continually deeper. The exploitation of the Main Sand was continued down the dip for a distance of over 1 mile, until the depth at which it lay was 3500 feet. (See Fig. 144.)

Good results were obtained throughout all this distance, a number of the deeper wells flowing 100-500 barrels a day. Thus this sand was proved to be saturated with oil, all the way down the

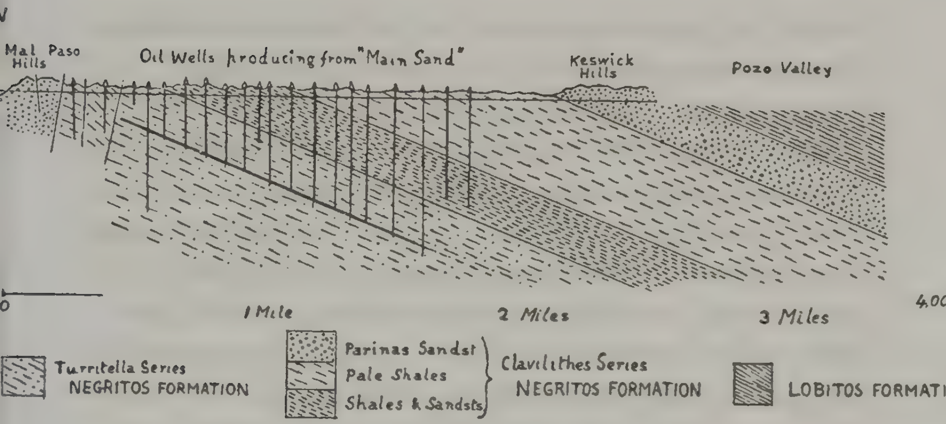


FIG. 144.—Diagram to illustrate the Exploitation of the "Main Sand," down the dip.
iagrammatic Section, from the Sea to the Pozo Valley, showing the old wells which obtained production from th "Main Sand," all the way down the dip for 1¼ miles, until the depth exceeded 3000 feet

dip, from near the surface down to a depth of 3500 feet.

At about this depth, two or three of the wells showed water, and a few others were only rather small producers. Attention then was turned to other productive sands above, which were exploited still farther eastward, with good results.

In the rich "Section 38," 4 miles south-east of Negritos, the results of the wells indicated a complex block-faulting which has had the general effect of upraising the central part of this area above its surroundings.

Except for the irregularities due to the cellular partitioning of the productive ground, the general result here is somewhat similar to that of an "anticline."

The same thing applies to the Negritos oilfield considered as a whole; for the productive area of the

oilfield is practically coincident or concentric with an area of up-faulted beds, and thus the effect is in some measure analogous to an anticline.

For around Negritos there is an area of some 12 square miles, in which rocks of the Negritos Formation have been brought up to the surface; and relative to the surrounding area of Lobitos beds, these rocks near Negritos have been pushed up to the extent of 5500 feet (the amount decreasing as we proceed away towards the outer parts of the field). The present productive area covers nearly all of the 12 square miles of Negritos rocks, and some 7 square miles of the surrounding Lobitos rocks, besides.

Origin of the Oil.

The oil-bearing formations in Northern Peru have originated under the same conditions as those of most petroliferous countries. As in other oil regions, the oil occurs not far from the shore-line, in a thick pile of shallow-water, marine sediments, which accumulated on a subsiding continental shelf.

Although the Littoral is so intensely affected by faulting, the field evidence does not connect the oil with the faults. The oil is not seen coming up through the fissures, and commonly, the least successful wells are those located on the large fault-lines. The more productive territory is that which is least broken.

By some writers it has been stated that the abundance of fossil shells associated with the oil-sands in Peru, are evidence of oil being derived from shell-fish and other animal matter. On investigation,

however, this evidence breaks down, for the seams of fossil shells which are so abundant are almost wholly beach-seams. They consist of beach-pebbles and shells which were cast up, empty, on the shore. Those which contained fish were opened and looted by birds.

Sandstones containing nummulites and other discoidal foraminifera, occur in the northern facies of the Lobitos Formation, which is productive at Lobitos; and also in the southern facies of this formation, which yields the oil at Lagunitas and in some parts of the Negritos field. But generally these seams are few, and careful search is necessary before any specimens are found. In very few seams are the foraminifera so numerous as to be an appreciable constituent of the rock.

The most probable source of the oil is vegetable material. In the Negritos Formation, the beds of clay-shales between the oil-sands, contain abundant specks of carbonaceous matter, and often many particles which clearly are fragments of plants. It is these carbonaceous clay-shales that smell strongly of petroleum. The amount of carbon still present in the shales is far greater than that of all the petroleum produced. It is not known whether these carbon particles represent marine plants or land plants.

The fossil tree stems in the Parinas Sandstone (Fig. 11), and frequent fossil wood in the beach-seams of all the formations, indicate that land vegetation was being drifted out to sea abundantly.

In the Zorritos Formation also, vegetable matter is conspicuous in the sand beds in the upper part of the accumulation.

It should be remarked, however, that in the Lobitos Formation the clay-shales are of fine texture, and usually do not contain visible carbon particles.

The carbon visible in the rocks is not, of course, to be regarded as a source of oil; but it is evidence for the former existence of much other vegetable matter, from which oil probably has been formed.

Water in the Sands.

The chief water trouble in the Peruvian oilfields has been lack of water.

In comparison with most other oilfields, the amount of water found in these rocks is very small. All of it is strongly saline.

There are two main classes of water in oilfields:

(1) The Upper Waters,—which have found their way into the sands, from the surface. This generally is met with only at small or moderate depth.

(2) The Under Waters,—which are indigenous to the rocks, and which are thought to belong to the original sea in which the sediments were deposited. This is the water which is found under the oil in a sand, and upon which the oil rests.

The Upper Water.

Most of the oil wells in Northern Peru have encountered no water at all,—either deep or shallow. There are, however, a few localities in which the rocks contain some water which has entered from their outcrops. This water, like any other water which

has stood in the desert, has absorbed a heavy charge of salt from the rocks.

Much water was found in the Parinas Sandstone at the north end of the oilfield, at depths of 500-1500 feet. Here the sandstones crop out along the coast, and in the sea; and it is obvious that the sea-water has penetrated down into them. The water was not uniformly distributed, but in different places it occurred at different horizons, and in different amounts. Some wells, after going through several hundred feet of water-bearing sands, struck oil in a lower bed of this formation; but in many cases the sands had been so much invaded that no oil could be found. Probably there would have been a rich oilfield in this vicinity if the sea-water had not entered it. The block-faulting, however, has put limits to the amount of mischief which the sea has been able to do.

One mile north-east of Negritos, there is a small area on the outcrop of the Negritos Formation, where, years ago, many wells encountered water at various depths, generally less than 600 feet. The water presumably had entered the sands at their outcrops, in years of flood. It damaged this locality for shallow production, though the same sands yielded oil farther eastward, lower down the dip. The underlying oil-sands here were not impaired, except in a few instances where the salty water corroded its way through the casing of the wells, and thus found access to the lower sands.

In the La Brea field, which gets a little rain every year, and also is much exposed to the periodic floods,

a considerable quantity of Upper Water is present. Although this water is very salt, it evidently is flood water which has soaked down through the superficial breccia deposit and has entered the outcropping oil-sands beneath. In certain places a valuable yield of water was found also on drilling down to the contact of the Tertiary beds with the mountain slates. (Along the edge of the mountains there are a few small springs similarly situated, the original source of the water being the precipitation—chiefly mist—with which the mountains are favoured.) This water, having about half the salinity of sea-water, can be successfully used in fresh-water boilers.

The Under Water.

One of the features of these oilfields, resulting from their block-fault structure, is the apparent absence of Under Water.

At a distance from the productive ground, in a number of places, deep-seated waters have been found in the deep test wells—such as the Lobitos Company's deep test in Quebrada Heath; the wells at Los Hervideros near Boca Pan; the deep holes at Cardallitos; and also several deep tests outside the Negritos oilfield. But within the oilfields there are few places where water has been found under the oil.

In the "Main Sand" of the Turritella Series, salt-water, which probably is Under Water, was encountered at depth, in two wells, situated $2\frac{1}{4}$ miles E.N.E. of Negritos. Here the exploitation of the Main Sand had been pursued down dip successfully.

for more than a mile, until the depth exceeded 3000 feet. But these two wells found salt-water mingled with the oil; and after a short time salt-water in large quantity appeared. This is the only instance in this oilfield, in which the presence of Under Water seems to have been demonstrated with certainty.

On the Salina, 5 miles south-east from Punta Parinas, some water trouble occurred in the rich territory known as Section 38, where the oil is obtained from the Parinas Sandstone Series, which is upwards of 1000 feet thick. The early wells struck the oil at 700-1000 feet, but in some of the wells in which the depth to the sand was considerably greater, much salt-water was encountered. In some of these instances the water was mixed with oil, and after a time the water was exhausted and the well produced oil. But in other instances the quantity of water seemed unlimited, and the wells were abandoned. It is not yet proved whether this is true Under Water, or whether it is water which has penetrated down into the rocks from the salina. The depths at which this water was found were 1800-2000 feet.

CHAPTER VI

CHARACTER OF THE PETROLEUM

General Description of the Peruvian Oil.

The petroleum of the oilfields in Northern Peru is a sweet-smelling limpid oil, of dark brown or greenish-brown colour.

It has a "mixed" base, and a low sulphur content. The specific gravity of the oil produced, ranges from ·79 to ·91 (47° Be. to 24° Be.), but, for the greater part of it, the figure lies between ·81 and ·85 (43·2° Be. and 35° Be.).

The crude oil yields 15-35 per cent of naphtha and gasoline, on distillation to 150° C.; and 30-50 per cent of kerosene, on continuing the distillation to 300° C.

The remaining less volatile portion of the oil yields excellent lubricants, or can be used as a first-class fuel oil, though generally it is considered too valuable to be thus consumed.

Comparison of Oil from the Several Fields.

The differences between the oil obtained in the several fields, or derived from the various formations, are not great.

The highest grade of oil was that obtained from a part of the Negritos field, 4 miles south-east of

FIG. 145.—The Refinery at Talara.

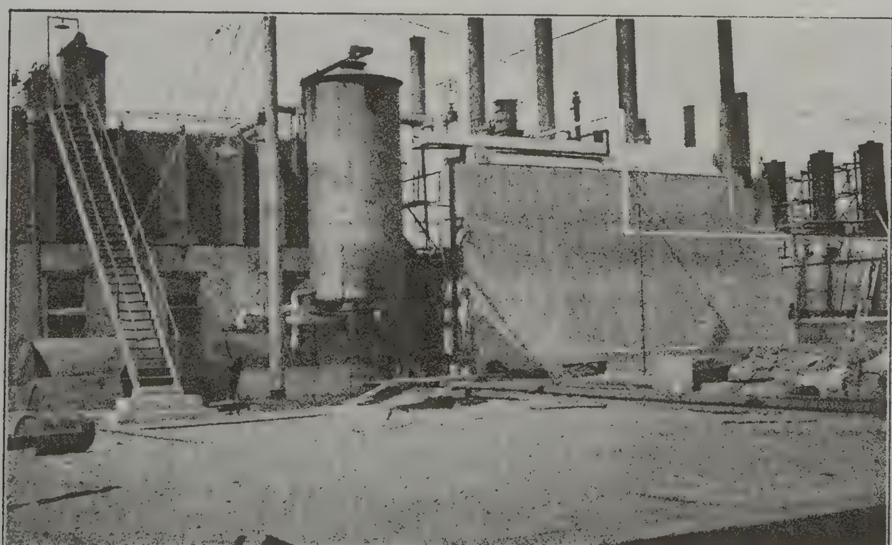


FIG. 146.—Refinery at Talara.
Some of the stills and condensers

Negritos, in the rich area known as Section 38, together with the adjacent south-west part of the Lagunitas plot. This oil, which came from the Parinas Sandstone of the Negritos Formation, had specific gravity about ·785-·805 (48°-44° Be.), and contained 30-35 per cent of gasoline (up to 150° C.).

In the Lagunitas plot of the Negritos oilfield, some of the deeper wells yielded a rather similar oil. This oil, which possibly also comes from the Parinas Sandstone, had specific gravity ·796-·812 (46°-42·5° Be.), and a gasoline content 24-36 per cent.

The oil of the Zorritos field, which is obtained from the Zorritos Formation, stands next in order, having an average specific gravity of about ·830 (38·4° Be.), and containing 15-30 per cent of gasoline.

This is closely followed by the oil from the field at Lobitos, which has specific gravity about ·838 (37° Be.), and a gasoline content of 25 per cent.

The oil from the Cabo Blanco-Restin field, which comes from the Negritos Formation, is rather heavier than the oil at Lobitos. It has specific gravity about ·85 (34·5° Be.) and contains 18-20 per cent of gasoline.

The oil from the Negritos Formation, in the Negritos field, which, until recent years, constituted the greater part of the output of Peru, varied from one part of the field to another. The specific gravity was generally between ·833 and ·854 (38°-34° Be.), and the percentage of gasoline was 17-23.

In this field some of the oil obtained from horizons undoubtedly in the Lobitos Formation, on the Lagunitas plot, had density ·84-·86 (36·5° Be.-32·6° Be.), and contained 15-18 per cent of gasoline.

Considerably heavier is the oil from the field at

La Brea. Here the oil also is darker and more asphaltic in character, than that of any of the other fields. The specific gravity is reported to be ·87-·93 (30°-20° Be.), and the gasoline content to be 5-7 per cent.

Density of the Oil.

The following table contains data from various sources. Figures given for specific gravity of the oil at the wells, are high in comparison with figures quoted as representative of the general output of the fields. These latter measurements have been made on oil in tanks, or on samples taken from ship cargoes received abroad: thus the apparent discrepancy is the result of the unavoidable evaporation losses which occur between the wells and the ultimate destination of the oil.

[TABLE

TABLE I.—DENSITY OF PERUVIAN CRUDE PETROLEUM

	Locality.	Particulars of Sample, etc.	Depth. Feet.	Density.	
				Sp. Gr.	Beaumé.
ZORRITOS.	Zorritos	*A published figure for the production		·830	38·4
	Zorritos	†A published analysis by G. E. Colby		·835	37·95‡
	Zorritos	†A published analysis by R. Fresenius		·8444	36·07‡
	Santa Rosa . . .	†Early wells		·8100	43·20‡
	Quebrada de Peroles	†A few old wells		·859	33·25‡
LOBITOS OILFIELDS.	Cabo Blanco-Restin.	†A published analysis by R. Sluter		·8519	34·6‡
	Cabo Blanco-Restin.	Mean density of Oil in tanks		·858	33·15
	Cabo Blanco-Restin.	Well No. 3 at Restin		·852	34·32
	Cabo Blanco-Restin.	Well No. 9 at Restin		·841	36·47
	Lobitos	*A published figure for the production		·841	36·47
	Lobitos	†A published analysis by R. Sluter		·8458	35·8‡
	Lobitos	Mean density of oil in the storage tanks		·843	36·1
	Lobitos	Well No. 293 "High-Cold-Test" oil	1775	·833	38·0
	Lobitos	Well No. 294 "Low-Cold-Test" oil	1618	·825	39·7
	Lobitos	Well No. 231		·826	39·49
	Lobitos	Well No. 235		·850	34·71
	Lobitos	Well No. 73		·872	30·55
NEGRITOS OILFIELDS.	Negritos	†A published analysis, by R. A. Duestua		·8498	35·0‡
	Negritos 1½ miles N.E. of village	"Main Sand," Turritella Series, Negritos Formation	2000-3000	·840	36·71
	Negritos at the village	Negritos Formation, old wells	500-1000	·850	35·0
	Negritos 2 miles E. of village	Clavilithes Series, Negritos Formation	1500-1800	·840	36·5
	Negritos N. end of field, 2 miles N.E. of village	Parinas Sandstones, Negritos Formation	1300-1800	·830	38·5
	Negritos S. end of field, 4 miles S.E. of village	Parinas Sandstone. Discovery Well in "Section 38"	985	·795	46·0
	Lagunitas plot . .	†A published analysis by R. Sluter		·8284	39·3‡
	Lagunitas plot West side	Early Wells	1500	·785	48·5
	Lagunitas plot West side	Lobitos Formation Early wells	500-600	·835	37·8
	La Brea district . .	Negritos Formation, 2 miles from its shore-line		·900	25·5

* *La Industria del Petroleo en el Peru*, R. A. Duestua, Lima, 1916.
† *Los Petroleos Peruanos*, R. A. Duestua, Lima, 1919.
‡ The relation between the figures for Specific Gravity, and for Degrees Beaumé, stated in this instance, is different from that fixed by the Bureau of Standards. These figures are quoted from the publications to which reference is made.

Calorific Value.

The calorific value of the crude oils is illustrated by the following published figures :[1]

TABLE II.

Oilfield.	Density of Sample. Degrees Beaumé.	Calories.	Authority.
Zorritos . . .	36·0	10672	*J. Salathe.
Lobitos . . .	31·5	10645	Bol. No. 50 del Cuerpo de Ingenieros de Minas del Peru.
Negritos . . .	34·95	10803	A. Beeby Thompson.

* J. Salathe, Titusville, Pa.

Sulphur.

The Peruvian oils contain only a very small percentage of sulphur. The following are the quantities recorded in published analyses :

TABLE III.

Oilfield.	Locality.	Density.		Sulphur per cent.	Analysis by
		Specific Gravity.	Degrees Beaumé.		
Zorritos .	Zorritos	·8444	36·07*	·041	†R. Fresenius.
Lobitos .	Cabo Blanco-Restin	·852	34·6*	·053	‡R. Sluter.
	Lobitos	·8458	35·8*	·064	‡R. Sluter.
Negritos .	Negritos	·8448	36·0*	·059	‡R. Sluter.
	Lagunitas plot	·8284	39·3*	·049	‡R. Sluter.
	La Brea district	·9452	18·2*	·041	‡R. Sluter.

* The relation, between the figures here given for Specific Gravity and for Degrees Beaumé, differs from that of the formula established by the Bureau of Standards. The figures are quoted from the works to which reference is made.
† R. Fresenius, Wiesbaden. ‡ R. Sluter, Inspector of Petroleum, New York.

Distillation Analysis of Peruvian Crude Oil.

The following table contains analyses of some of the crude oils of the Peru fields.

These analyses show the percentages of the distillates obtained between the conventional temperature limits.

The product distilled between 0° and 150° C. is classed as gasoline.
" " 150° – 300° C. " " kerosene.
" " 300° – 315° C. " " gas oil.

The residue, after 315°, is classed as heavy oil from which lubricants and fuel oil can be made.

[1] *Los Petroleos Peruanos*, R. A. Duestua, Lima, 1919.

TABLE IV.—DISTILLATION ANALYSES OF PERUVIAN CRUDE OILS

Field.	Locality.	Particulars of Sample.	Crude Oil.			Gasoline. 0°-150° C. 32°-302° F.		Kerosene. 150°-300° C. 302°-572° F.		Gas Oil. 300°-315° C. 572°-600° F.		Heavy Oil. Residue above 315° C. Residue above 600° F.		
			Depth of Wells.	Specific Gravity.	Density Beaumé.	Per Cent.	Density Beaumé.	Per Cent.	Density Beaumé.	Per Cent.	Density Beaumé.	Per Cent.	Density Beaumé.	Cold Test.
ZORRITOS	Zorritos . . .	*Published Analysis by R. Fresenius	..	·8444	36·07†	29·3	57·78	46·61	..	..	..	..	..	..
LOBITOS	Cabo Blanco-Restin	Tanks of oil, representing the field	..	·8581	33·15	18·0	59·3	37·5	38·25	4·25	..	40·25	..	High
	Cabo Blanco-Restin	*Published Analysis by R. Sluter	..	·8519	34·6†	20·0	54·5	..	..	..	..	35·90	20·7	..
	Lobitos . . .	Tanks of oil, representing the field	..	·8425	36·17	22·0	59·97	39·0	41·7	3·5	..	35·5	..	Low
	Lobitos . . .	Well No. 294	1618	·8249	39·7	26·0	59·4	41·50	41·8	3·75	..	28·75	..	Low
NEGRITOS	Negritos . . .	*Published Analysis by R. Sluter	..	·8448	36·0†	30·4	53	..	..	..	..	35·10	21·2	..
	Negritos . . .	‡Oil from Negritos Formation. Old wells at Negritos	..	·845	35·7	22·5	..	34·5	..	3·00	..	40·0	..	..
	Negritos 1½ miles N.E. from village	‡Oil from "Main Sand" in Turritella Series	2000 to 3000	·837	37·4	18·0	..	39·0	..	3·0	..	40·0	..	..
	Negritos 4 miles S.E. from village, S. end of field	‡Oil from Parinas Sandstones. Early wells in "Section 38"	1000 to 1500	·80	44·5	31·0	..	44·0	..	2·5	..	22·5	..	..
	Lagunitas plot .	‡Early production	..	·829	38·8	29·0	..	40·0	..	3·0	..	28·0	..	..
	Lagunitas plot West part	‡Early wells	900 to 1500	·820	40·7	33·0	..	38·0	..	2·5	..	26·5	..	..

* *Los Petroleos Peruanos*, R. A. Duestua, Lima, 1919.

† The relation between the figures given, in this instance, for Specific Gravity, and for Degrees Beaumé, is not identical with that of the formula adopted by the Bureau of Standards. The figures here are quoted from the publication to which reference is made.

‡ Generalised values.

Commercial Distillation Results.

In refining high-grade crude oils, the temperatures at which the various commercial products are separated are not the same as those used in the above-listed laboratory tests.

In most cases, the distillates obtained up to a temperature considerably above 150° C., are suitable for inclusion with the products classed as gasoline.

The yield of gasoline is thus greater, and that of kerosene smaller, than the figures represented by the analyses above.

Also commonly, the quantity of kerosene is further decreased, by grouping with the gas oil the distillates obtained at temperatures somewhat below 300°.

The commercial products of distillation of Peruvian oil are illustrated by the following results, obtained (by R. A. Duestua) on treatment of a characteristic sample of Negritos crude oil.[1]

TABLE V.—COMMERCIAL PRODUCTS OBTAINED ON SIMPLE DISTILLATION OF SAMPLE OF NEGRITOS CRUDE OIL OF DENSITY ·8498 (35° BE.)

Products	Distillation Temperature (Fahrenheit).	Density Beaumé.	Mean Boiling Point (Fahrenheit).	Flash Point	Viscosity at 212° F.	Viscosity at 100° F.	Percentage.
Gasolines and naphthas .	0-338	56·2	265	..	..	..	24·2
Lamp oils .	338-536	39·2	450	..	..	..	24·8
Gas oil . .	536-600	30·4	..	250	..	47	14·8
Lubricating oil	..	23·4	..	365	..	285	23·4
Residue . .	..	11·4	..	545	1050	..	15·6
Loss . . .	..	..	..	..	..	..	3·6

Gasoline from Peruvian Crude Oil.

The character of the gasoline distillates is indicated by the following published analyses (see Table VI.):[2]

[1] *Los Petroleos Peruanos*, by R. A. Duestua, Lima, 1919.

[2] *Ibid.*

Table VI.—Analyses showing Gasoline Products obtained by Simple Distillation

Oilfield.	Locality.	Density of Sample Beaumé.	Light Gasoline.			Heavy Naphtha.			Analysis by
			Distillation Temperature (Fahrenheit).	Density Beaumé.	Per Cent.	Distillation Temperature (Fahrenheit).	Density.	Per Cent.	
Zorritos .	Zorritos	?	0-176	?	11·8	176-302	?	11·1	J. Salathe
Lobitos .	Restin	34·6	0-250	65	10·2	250-302	54·5	9·8	R. Sluter
	Lobitos	35·8	0-250	64·8	13·2	250-360	52·1	17·6	R. Sluter
Negritos .	Negritos	36	0-250	65	14·2	250-302	53	16·2	R. Sluter
	Launitas	39·3	0-250	64·9	14·6	250-330	53·1	15·7	R. Sluter

Table VII.—Analyses showing Kerosene Products obtained by Simple Distillation

Oilfield.	Locality.	Density of Crude Beaumé.	Percentage of Gasoline previously distilled over.	Kerosene Distillation.		Properties of the Distillate.				
				Temperature of Distillation (Fahrenheit).	Percentage obtained.	Density.	Flash Point.	Viscosity.	Colour.	Sulphur per Cent.
Lobitos .	Restin	34·6	20	302-554	36·8	39·7	73	365 at 130°	6 Standard white very cloudy	·012
	Lobitos	35·8	30·8	360-554	22	40	122	440 at 60°	10 Standard white	·014
Negritos	Negritos	36	30·4	302-554	23	40	112	400 at 60°	10 Standard white	·011
	Lagunitas	39·3	30·3	330-554	31·51	44	100	385 at 60°	12 Standard white	·011

Kerosene from Peruvian Crude Oils.

The properties of the illuminating oils are indicated by the figures in Table VII. (see preceding page), which are in continuation of the analyses [1] shown in Table VI.

Gas Oil from Peruvian Crude Oils.

After the products suitable for illuminating oil have been obtained, the distillation is continued until a temperature of 600° F. is reached. The gas-oil, resulting from this process, is a cloudy yellow heavy oil.

The character of this product is expressed by the figures in Table IX. (see following page), which are in continuation of the analyses [2] contained in the two preceding tables. The properties of the residual oil also, are shown in this Table IX.

Lubricating Oil.

The residual oil after distillation of the gas oil, yields light lubricants of high quality, and therefore is generally too valuable to be used as fuel oil.

Lubricants similar to the following Pennsylvania brands, according to R. A. Duestua, are produced from the Peruvian crude:

TABLE VIII.

	Density.	Viscosity at 100°.	Flash Point.
Extra white rose	33·5-34·5	88-95	355-365° F.
Pale neutral	30·0-31·0	140-150	390-400° F.
Red neutral	29·0-31·0	162-172	395-410° F.

[1] Analyses by R. Sluter of New York.
[2] *Los Petroleos Peruanos*, by R. A. Duestua, Lima, 1919.

TABLE IX.

Oilfield.	Locality.	Density of Sample Beaumé.	Percentage of Gasoline distilled.	Percentage of Kerosene distilled.	Gas Oil.			Residue.				Analysis by
					Distillation Temperature.	Density Beaumé.	Percentage obtained.	Percentage remaining.	Density Beaumé.	Viscosity.	Flash Point (Fahrenheit).	
LOBITOS .	Restin	34·6	20·0	36·8	554-600	30·2	6·6	35·9	20·7	298 at 330° F.	330	R. Sluter
	Lobitos	35·8	30·8	22·0	554-600	32·8	10·6	36·0	20·2	433 at 130° F.	330	R. Sluter
NEGRITOS	Negritos	35·0	24·2	24·8	536-600	30·4	14·8	..	..	..	..	R. A. Duestua
	Negritos	35·4	24·0	34·0	536-600	30·0	12·0	..	..	..	..	F. C. Robinson
	Negritos	36·0	30·4	23·0	554-600	33·0	10·7	35·1	21·2	440 at 130° F.	330	R. Sluter
	Lagunitas	39·3	30·3	31·5	554-600	33·7	8·1	29·4	22·0	334 at 130° F.	335	R. Sluter

TABLE X.

Oilfield.	Density Crude Sample.	Percentage of Gasoline distilled.	Percentage of Kerosene distilled.	Percentage of Gas Oil Distillate up to 600° F.	Lubricating Oil.				Residuum.			
					Percentage.	Density.	Viscosity at 100° F.	Flash Point.	Per Cent.	Density Beaumé.	Viscosity at 100°.	Flash Point.
*Negritos	35·0	24·2	24·8	14·8	17	23·4	285	365	15·6	11·4	1050 at 212°	545
†Negritos	35·4	24·0	34·0	12·0	16	22·0	280	380	16·0	14·0	..	600

* Analyses by R. A. Duestua, *Los Petroleos Peruanos.*

† Analyses by F. C. Robinson, *Los Petroleos Peruanos.*

"Low-cold-test" Oil.

A feature of the Peruvian lubricating oil is its low solidifying point.

In the Lobitos field, for example, about a third of the wells yield these low-cold-test oils. This oil is kept apart from the oil produced from the other wells,—separate pipe-lines and tanks being used for it.

At present there is no means of telling which class of oil a well will yield; and consequently, the oil from every well is tested separately. Often two wells, side by side, and apparently producing from the same sand, will yield oils which differ in this respect. Also a well may give low-cold-test oil from one bed, and then when the hole is deepened, it may yield high-cold-test oil from another bed. Commonly the low-cold-test oil comes from the shallower wells yielding rather heavier oil.

The following is a practical test for low-cold-test crude, which is carried out on the residue from the crude, after simple distillation up to 600° F. This residue oil is distilled in a flask, until 60 per cent of its volume has passed over. This distillate is collected in 3 portions or cuts, each being a 20 per cent fraction. Then these three "cuts," which represent the lubricating oil, are subjected to low temperature. If all three portions remain liquid at 0° centigrade, the oil is said to be a low-cold-test oil.

Residual Oil.

The residuum, left after the lubricating oil has been distilled off, is a dense viscous oil, which may

be used as heavy fuel or may be blended with lighter fuel oil.

The foregoing published figures (Table X.), which are in continuation of two of the analyses contained in the preceding tables, indicate the character of this residue after the lubricating oil has been distilled.

CHAPTER VII

PRODUCTION

Output per Well.

The oilwells of the Peruvian fields, in general, are not large producers. Some of the wells, however, have yielded as much as a quarter of a million barrels of oil, and there are also a very few which have produced half a million barrels. Fortunately the drilling is easy, and the life of the wells is long.

In the **Zorritos** Field most of the wells are rather small producers: not many hundred-barrel wells have been obtained. One of the best wells was No. 313, which flowed at the rate of 250 barrels a day.

In the **Lobitos** Field a number of the deeper wells (2500-4000 feet) have flowed as much as 500 barrels a day, or more; and some of them have flowed for over two years. Well No. 100, for example, yielded 110,000 barrels of oil in twenty-five months.

In the **Negritos** and **Lagunitas** Field, in former years, a number of the best wells in the richest territory, commenced production at 250-600 barrels a day. The average initial yield was about 35-40 barrels a day.

In each of the oilfields many of the old wells are kept producing, although their daily output may now be no more than one barrel of oil. Two or

Photograph by T. O. Bosworth, 1913.

FIG. 147.—Lowering Casing.

A view inside the derrick during the drilling of Well No. 672, the second well in the rich area known as Section 38, on the Salina, 4 miles south-east of Negritos.

Photograph by T. O. Bosworth, 1913.

FIG. 148.—Screwing Casing.

A view inside the derrick during the drilling of Well No. 672, the second well in the rich area known as Section 38, on the Salina, 4 miles south-east of Negritos.

Photograph by T. O. Bosworth, 1913.

Fig. 149.—"Pulling sucker rods," for cleaning the pump at one of the old wells in the Negritos Oilfield.

Light derricks are kept over the pumping wells for this purpose.

Photograph kindly lent by the Lobitos Oilfields Ltd

Fig. 150. A Flowing Well at Lobitos (Well No. 188).

three of the first twenty wells at Negritos, drilled about twenty-three years ago, are still pumping a few barrels a day.

The average yield of the wells kept in production, is indicated by the following figures:

Zorritos field (1915) . .	27 wells	9·2 barrels a day
Lobitos and Cabo Blanco field (end of 1920) . . .	163 „	12·4 „
Negritos and Lagunitas field (end of 1921). (Figures conjectural, deduced from statements published) .	870 (?) „	9·4 (?) „

Yield per Acre.

[Statistics and examples from various parts of the oilfields, illustrating the productivity of the oil lands, had been prepared for this chapter; but in deference to the wishes of one of the oil companies, this material, together with production graphs, decline curves, details of the wells, etc., have been excluded.]

A rough calculation, however, using only facts which are available to the public, gives a general idea of the productivity of the Peruvian oil lands, per acre.

Since the total quantity of oil produced is about 34 million barrels, and since the total area which has been drilled over is about 15,000 acres, it follows that the proven fields have already yielded some 2250 barrels per acre.

Much of this area is only newly drilled, and nearly all the old ground is still producing. Hence it may be inferred that the oilfields contain, on an average, not less than 5000 barrels of oil per acre, and that the richer areas must contain at least 10,000 barrels per acre.

Productivity of the Formations.

Observations and statistics, covering a number of years, lead to some interesting conclusions in connection with the productivity of the various formations and oil-sands. These, unfortunately, it is not permissible to publish here.

The following, however, is a rough estimate of the proportion in which the several formations have at present contributed to the oil output of Peru:

Zorritos Formation	5·85	per cent
Lobitos Formation—northern facies	20·00	,,
Lobitos Formation—southern facies	13·30	,,
Negritos Formation, Parinas Sandstone only	16·00	,,
Negritos Formation, beds beneath Parinas Sandstone	44·00	,,
Formation productive near Lake Titicaca	·85	,,
	100·00	,,

Statistics of Production.

The following tables contain particulars of the output of oil from the Peruvian oilfields.

(Details as to the several sources of information are appended.)

[TABLE

No. 1. PRODUCTION OF THE OILFIELDS OF PERU

(In Imperial tons, of 2240 pounds ; and in some instances, in metric tons of 7½ barrels)

Year.	Zorritos.	Lobitos and Restin.	Negritos and La Brea.	Lagunitas.	Pirin, Lake Titicaca	Total of the Production here recorded
	"Metric" tons.	Imperial tons.	Imperial tons.	Imperial tons.	Imperial tons	"Tons"
1896	6,338	..	..	..	..	6,338
1897	9,127	..	..	..	..	9,127
1898	9,156	..	..	..	..	9,156
1899	11,888	..	..	..	..	11,888
1900	13,731	..	†26,198	..	..	39,929
1901	9,952	..	†29,125	..	..	39,077
1902	7,903	..	†25,073	..	..	32,976
1903	6,540	..	†32,562	..	..	39,102
1904	6,603	..	39,508	..	..	46,111
1905	5,029	*10,000	44,688	..	..	59,717
1906	5,655	21,600	44,068	..	179	71,502

No. 2. PRODUCTION OF THE OILFIELDS OF PERU

(In barrels, of 35 Imperial gallons or 42 American gallons)

Year.	Zorritos.	Lobitos and Restin.	Negritos and La Brea.	Lagunitas.	Pirin, etc., Lake Titicaca.	Total of the Production here recorded.	Total Production according to U.S. Geological Survey Statistics.
1896	47,536	..	..	..	..	47,536	47,536
1897	68,452	..	..	..	..	68,452	70,831
1898	68,571	..	..	..	..	68,571	70,905
1899	89,166	..	..	..	..	89,166	89,166
1900	102,976	..	†203,860	..	..	306,836	274,800
1901	74,643	..	†226,638	..	..	301,281	274,800
1902	59,274	..	†195,116	..	..	254,390	286,725
1903	49,047	..	†253,380	..	..	302,427	278,092
1904	49,524	..	307,432	..	..	356,956	345,834
1905	37,720	76,000	347,729	..	..	461,449	447,880
1906	42,419	164,160	342,915	..	1,365	550,859	536,294
1907	65,476	282,720	412,420	..	15,000	775,616	756,226
1908	71,429	324,163	566,602	..	76,103	1,038,297	1,011,180
1909	70,750	434,918	769,797	..	76,103	1,351,568	1,316,118
1910	107,000	405,414	801,058	‡4,653	50,000	1,368,125	1,330,105
1911	94,048	396,507	837,821	70,936	30,000	1,429,312	1,308,274
1912	78,095	594,875	1,000,830	114,223	15,000	1,803,023	1,751,143
1913	83,343	564,786	1,184,261	218,094	10,000	2,060,484	2,133,261
1914	88,136	511,472	1,045,580	289,295	10,000	1,944,483	1,917,802
1915	72,736	673,839	1,415,028	401,329	1,000	2,563,932	2,487,251
1916	73,852	670,381	1,318,599	563,050	..	2,626,482	2,550,645
1917	75,262	695,750	1,806,928		..	2,577,940	2,533,417
1918	•76,190	647,619	1,820,814		..	2,544,623	2,536,102
1919	•80,000	695,157	1,862,964		..	2,638,121	2,616,000
1920	•93,698	739,450	1,993,331		..	2,826,479	2,816,649
1921	•95,000	789,511	•2,696,098		..	•3,578,609	•3,568,220
..	1,914,343	8,666,722	23,069,381		284,571	33,935,017	33,415,256

• Estimated † Not including oil consumed as fuel. ‡ All produced in January.

imperial tons; and the monthly statistics of production, which are published, are thus in imperial tons. The ton of Lobitos oil contains about 7·6 barrels of oil.

In the Negritos field the figure for volume has been daily converted to imperial tons; and until 1914, all statements of production were thus expressed. Later, the results have been recorded monthly, both in barrels and in imperial tons.

The first of these two tables gives the production in tons. In the case of Zorritos these are metric tons, but for the other fields they are imperial tons.

The second table gives the results in barrels; but in each table it has been needful to convert some of the quantities either from volume to weight or else from weight to volume;—and to do this it has been necessary to assume the specific gravity to be the average of that in other years.

For the Zorritos field, in Table II., the figures for 1896–1904 are obtained from Redwood's *Treatise on Petroleum*—where the production in gallons is stated. The figures for 1905–1918 are taken from *Petroleum in 1911* and *Petroleum in 1918*, published by the United States Geological Survey. The figures in Table I. are deduced from those in

Table II., by dividing by 7·5 and thus converting barrels to "metric tons."

For the Lobitos field, in Table I., the figures given for 1905–1918 are taken from the U.S. Geological Survey annual publications on Petroleum Production. The figures for 1919–1921 are from the returns in tons, published in British journals. The figures in Table II. (barrels), for all these years, are obtained by multiplying by 7·6.

For the Negritos field the statistics for 1900–1903, shown in Table II., are from old records. These are for net production, in imperial tons; they do not include the oil consumed in the field and refinery, which amounted to several thousand tons a year. The figures for these years, placed in Table I., were obtained by assuming 7·7815 barrels to the ton, which was the average for a number of years.

The figures for 1904–1906 in Table I., were taken from the U.S. Geological Survey's annual volume on Petroleum Production. In that publication they are recorded as "metric tons," but they evidently are the gross production in imperial tons. In Table I., these quantities have been converted to barrels, on the basis of 7·7815 barrels to the ton. The figures for 1907–1914 in Table I. are from records of gross production, in imperial tons of 2240 pounds.

In Table II. these returns are expressed in barrels in accordance with the specific gravity of the oil, there being at that time generally about 7·8152 barrels to the ton.

The figures for 1914–1919 are the field statistics of the gross production. They have been carefully recorded, both in barrels and in imperial tons.

The quantities entered for 1920 and 1921 are taken from journals recently published. In the journals they were expressed in barrels. In Table I. these quantities have been converted to tons by dividing by 7·8152.

For the Lagunitas field, for the years 1906–1915, the figures represent net production. The record was kept in imperial tons.

The figures in Table II. have been obtained by converting the tons to barrels, in accordance with the specific gravity of the oil.

The figures for 1916 are gross production, and were recorded both as imperial tons and as barrels. The production from 1916 onwards, in which year the property was sold, is incorporated with the Negritos production.

For the Pirin field, the figures are taken from the U.S. publications on Petroleum Production, in which they are expressed in barrels. Apparently these quantities are only rough estimates. In two years the figure 76,103 barrels is given, which evidently is intended as the equivalent of 10,000 imperial tons of this oil.

The figures in Table I. therefore have been calculated from those in Table II., on this understanding.

The right-hand column of figures in Table II., showing the total production (in barrels) of Peru, year by year, is copied from the U.S. publications on Petroleum. These figures do not agree exactly with the quantities entered in the other columns.

A further column therefore is included, showing the actual totals, year by year, of the output of all the fields as recorded in the other columns

It is to be observed that the production of the Negritos field in its early years has not been recorded, and also that, both at Negritos and Lagunitas, for several years the oil consumed in the fields is not included.

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THE END

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